HOUSE ORGAN OF ALLOYS To Be GENERAL ALLOYS COMPANY

ALLOY PROGRESS

EDITED BY [signature] PRESIDENT

Bright Spot in Metal Progress

ENTIRELY ABOUT HEAT & CORROSION RESISTANT ALLOY CASTINGS

Come to the Steel Show

You earn your living in American Industry, and *you* progress as your Company and your industry *progress.*

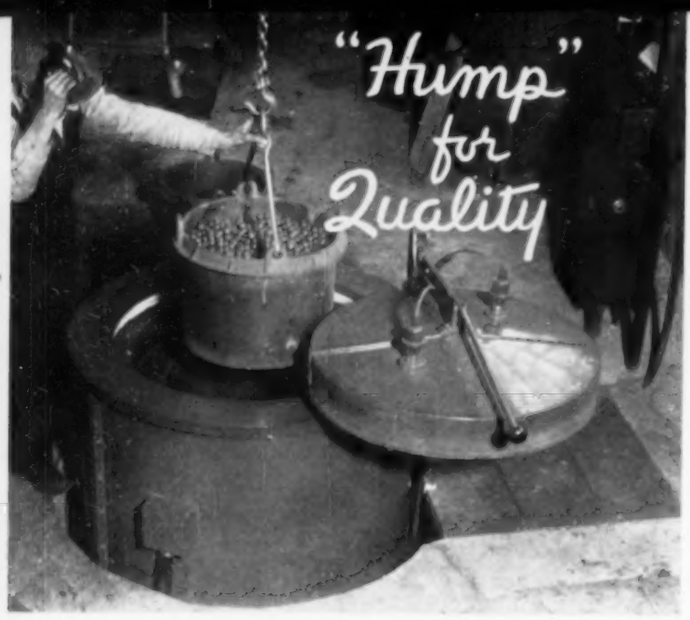
Once each year the progress of the Metals Producing, Fabricating, and Heat Treating Industries is set clearly before those who *take time* to come,—see,—and learn.

Great strides have been made in 1936–1937 and the Atlantic City Show will surpass any industrial exposition ever held. *A conservative statement.*

General Alloys have been the largest exhibitor in our line for 18 consecutive years, accepting and *fulfilling the responsibility of* LEADERSHIP OF AN INDUSTRY.

[signature]

18 YEARS Consecutively General Alloys Company have been largest exhibitors in their line at the steel shows. We have carried more advertising with A.S.M. and A.S.S.T than all competitors combined.



I SNAPPED the above shot of Universal Newsreel's "flying platform" with Irving Smith turning the camera, at the International Yacht Races off Newport—America's Cup Races—if the word "Race" is applicable. Smith asked for a shot "Right on my coat-tails." Those "Flying Platforms" are old Curtiss Fledglings, with large low-pitch props. They can fly at 35 M.P.H., squash-stall at 25, or literally "stand still" in a 25 mile wind. While taking pictures of the Queen Mary going up-wind, she ran away from them. Flying the thing is like riding a dish-rag. Urban Santone does the same job for Paramount News.

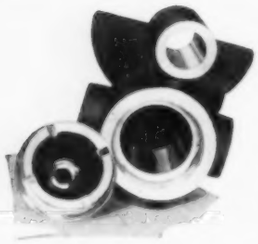
WELL, ye M.P. Editor, Ernest Thum, is to blame for starting something when he printed my first air-photos. To date, they have had over six million circulation, or about three times all A.S.M. circulation for all time. New York Times, (front page of Rotogravure section reproduced herewith), leading papers in twenty-two principal cities, carried my race pictures. More will appear in "Spur," "The Sportsman," Yachting publications, etc.

The N. Y. Times picture was a "beat" on the press cameramen at the start of the second race. I flew on instruments from Providence over fog and hit the race by luck.

THIS "monkey-business," (non-flyers' name for it), consumed my four day vacation, and about twelve hours total flying time over water. Next time I fly over water for twelve hours it will be to London. I would rather not sit down on a covey of masts, if I have the good l to discriminate. It all started when Times" of London cables J. Scott Hug appoint me Official Aerial Photographer f the Races. An excellent excuse for a goo

IF there is any "Ringside" at a yacht it is the press planes flying low on passes from the Coast Guard. As I ha pictures while flying the plane I must left. Pilots carrying passenger photogr in closed ships prefer to circle right. T flock of planes in the air ranging from Transports to Coast Guard Grummans, t bilt's "Air Yacht" and miscellaneous s planes, having about 300% difference in speed, the traffic problem on the turna triguing. When the Coast Guard Grum dive at you, for flying too close, the

THE first day I scorned a "Press" sig my plane, and the Coast Guard, insp press permits by plane numbers, tried to me off when I approached the racing p The observer would hold up ten spread fi three times signifying "Stay away 300 and I would signal back with ten fingers h and get a dive from the Grumman. It w but it interfered with the photography. bought enough surgeon's tape to bandag Republican Party and stuck it on m "PRESS." Fully as "Permanent" as the manent Ductility" Alloy Technicrapters



Birds of a Feather

LEEDS & NORTHRUP furnaces, like Leeds & Northrup pyrometers, have always stood for the maximum in quality and precision. Leeds & Northrup would no more think of compromising with quality by "saving" a few cents a pound with some second-rate alloy than they would think of cheating on their fire brick or on the copper in their instruments. Q-Alloy is standard equipment in Leeds & Northrup furnaces.

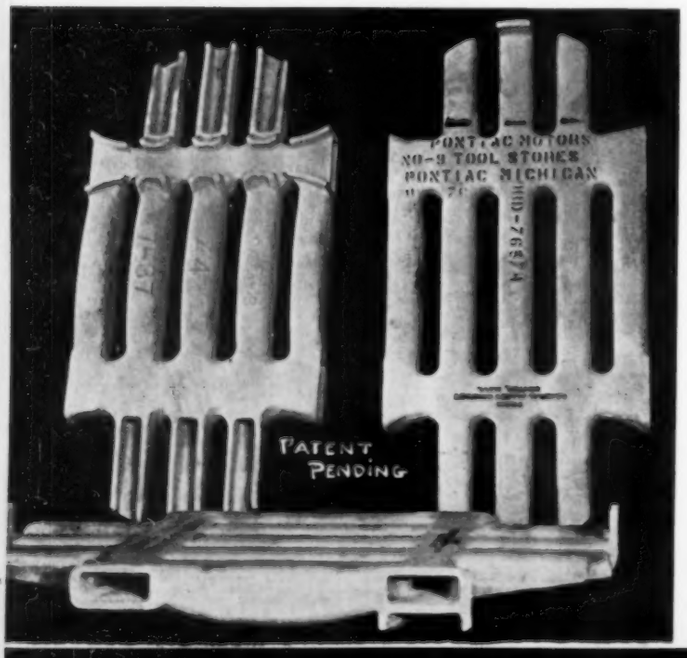
WE Asked the International Yacht Racing Authority, J. Scott Hughes, to explain about sails. His sketch of the "Mae West" and "Greta Garbo" types are reproduced herewith for their artistic merit.

THE design of Ranger's hull, biggest factor in her speed, was developed in the towing tank of Stevens Institute at Hoboken. Another distinguished Stevens product, no tank, is R. G. Hess, C. I. Hayes' N. Y. Representative. "EXPERIENCE WON THE RACE," said a Committee Member, "Experience, engineered into Ranger, summing up the 'know how' behind 'Mike' Vanderbilt's success."

EXPERIENCE, engineered into Q-Alloys & X-ite, is the basis of the outstanding service economies that accrue to those who **themselves** possess enough experience to pay a little more in the beginning to save ten-fold in the end. We freely admit that the best is too good for some people, who sponsor Support and ultimately attain Mediocrity.

WHEN you can't use hinged trays for lightness and long life and must have a rigid tray the tubular design shown below and variations thereof are the most rigid obtainable and are an exclusive General Alloys development.

WHETHER it's flow reversing valves or high pressure fittings of complex design General Alloys foundry practice has made possible many new applications of corrosion resisting castings.

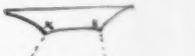


International Yachting Authority Explains S

My dear Mr. Harris.

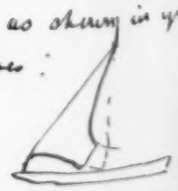
① ANNIE Oakley = a spinnaker with holes punched in it [name (won the free ticket in this county, after a female shot of that name) on the theory that the holes will let the dead air escape. American yachts do not much go in for annie Oakleys.

which if laid out [illegible] would look something



The two sheets being [illegible] at the X

The latest sail of N[illegible] design is Rangers dra[illegible] ~~Genoa~~ GENOA is an extra large jib) letting as shown in your pictures:



② Mae West is the big spinnaker with the enormous chest! — parachute spinnaker.

and ③ Greta Garbo is so self-explanatory!

The double-clewed jib

Sherman Hoyt calls [illegible] Montague — I don't [illegible] why. Yours sincerely

J. Scott [illegible]

Q-ALLOYS THE QUALITY NAMES IN ALLOY FOR HEAT CORROSION ABRASION X-ite

Sunday.
ugust 8, 1937

The New York Times

Rotogravure
Picture Section 9

ENDEAVOUR II

BRITAIN TRIES FOR THE SIXTEENTH TIME TO LIFT THE AMERICA'S CUP

Ranger, the defender *(at the left)*, sailed by Harold S. Vanderbilt, and T. O. M. Sopwith's Endeavour II, the challenger, photographed as they emerged from the fog after the start of the second race of the series off Newport.—*(Sky View by H. H. Harris, President General Alloys Company, Boston.)*

In Circle—Harold S. Vanderbilt and T. O. M. Sopwith *(right)*.—*(Associated Press.)*

In the Circle, Lower Left—Ranger photographed from the air after crossing the finish line in the second race.—*(Sky View by H. H. Harris.)*

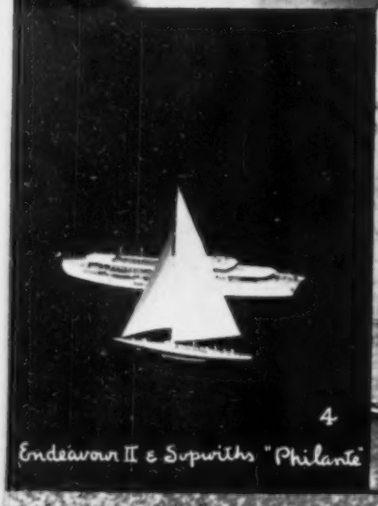
Races Won on a Draughting Board

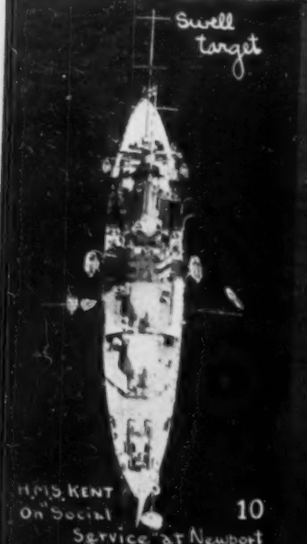
The America's Cup Races, 1937, were won on a draughting board. "Mike" Vanderbilt's Ranger was ENGINEERED AHEAD, before the race started. Engineering based on *Experience.*

Q-Alloys and X-ite, *All-American Alloy Winners,* "Got there" by the same "Brain Route." Superior engineering based on the *unequalled experience of* the oldest and largest exclusive manufacturer of Heat and Corrosion Resistant Alloys, *General Alloys, of Course!*

RANGER

NO FURNACE IS BETTER THAN ITS ALLOY PARTS

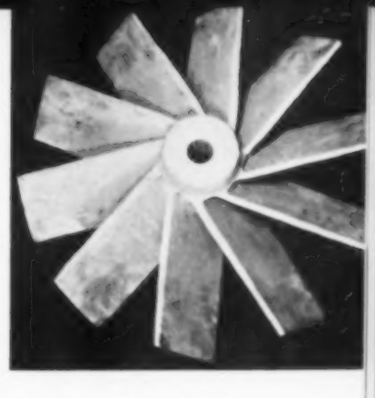




If I can pass on to you through these amateur snapshots one tenth the "lift" I get from viewing the originals,—I'll be glad I lugged along the old "Brownie." If you don't like the sea, the sun and the clouds and ships that sail into them,—you don't deserve good alloy. Remember, I'm no amateur in the alloy business. Precision, coordination and proven technique is still quite rare and alloy amateurs abound.

WILLIAM A. DAVIDSON
(1870-1937)

Air Photo by H.H.H.



BALANCED

WE make a specialty of balanced high speed fans, open and closed impellers, and have made more than sixty different designs. The fan may be a small part of the furnace but it's an awfully poor place for a furnace builder to chisel on alloy.

TRIBUTE TO A MAN...

Editor's note—This extract is taken with permission from the "Enthusiast," publication of the Harley-Davidson Motor Co. of Milwaukee. Mr. Davidson was Vice-President).

THEY thronged from all walks of life, men and women of all creeds, all nationalities, the humble and great, to do reverence to the man they loved . . . Wil-A. Davidson. Everyone treasured some kindly deed, word of advice, some act of help, the memory of which d up in the heart with a wave of emotion. Here was friend . . . a friend of man . . . a man.

ND with the many things occupying his mind, he never lacked the time to attentively listen to the ms and cares of his fellow men . . . his door was always open . . . always there was the welcome, "Come in." Always there was priceless advice appreciated by those of high or low degree. Dealers visiting the factory liked to spend much time with him. Bankers, manufacturers, politicians confided in him. Not an employee who did not feel free to drop in and see him any time about any question or problem.

"THAT his compassion and his good deeds were boundless, you would expect of such a man. If they were publicized, volumes could be written. The needy, the heart-broken, those in pain and distress, were not passed by.

"TO have known William A. Davidson, to have worked with him, to have been associated with him, was indeed a rare privilege. His example, his precepts, his deeds, have left their influence on all those with whom he came in contact. The world is happier, more cheerful, and better for his having been among us."

OM WHERE I SIT...

Continued from page 294

ITE this in a Rochester hotel. The House-per just poked her head in unannounced. t you taught to knock when you were le girl?" I asked. "Uh-huh," she replied, 'm a big girl now, and I have more fun ocking."

don't know what Traffic is until you've en a "Spectator Fleet" at this yacht race, nds of yachts swarming thirty square Forty or fifty of them being Navy or Guard and carrying politicians, relatives ess; a swell holiday at taxpayers' expense. Beas the U. S. Dog can carry and still the modern miracle.

ORE the races the British were even ssey. Most Americans—feeling that Sop-had been short-changed on the previous re hoping that "Mike" Vanderbilt would good shellacking. The first race was pa-Endeavor 2 losing by the greatest time in history. Ranger sailed closer, faster, s seemed to fill better and her crew drilled to precision. Slow slacking of ys, crew taking positions which gave Sopwith's moves in advance, other sloppy was visible from the air.

SOPWITH asked for a day out, his prerogative under the rules, and promptly dry-docked Endeavor to look for surplus anchors, lobster-pots. Finding none, he took out considerable ballast, rushed a new sail, and the rest is a sad, sad story that you already know. Great guy this Sopwith, graduated off a work bench like many of our outstanding industrial leaders, and made millions building war planes for the allies. He learned the combination and is now cleaning up right getting the British ready for the next war. Soon a fresh crop of munitions millionaires will be fighting for another crack at "The old Mug." Sopwith is no sap sailor. He out-maneuvered Vanderbilt on starts, did a generally good job. He sailed a much slower boat and bought the most expensive course of yachting lessons in the world from the "Old Maestro" Himself. Like most General Alloys competition he "went to bat with a Clothes Pin." Sopwith proves there is still leaven in the British loaf.

NILS NILSON, Chicago's Swedish Ambassador to Germany, is now A.P. "Natzi" Correspondent. His first dispatch: "Nilson toasts U.S.A. in German Sanger-Jernts 'Here's to the Land I love'—and vice versa."

FLYING over Long Island, we spot a small estate with a 30 gal. swimming pool and two hole golf course. "What could be more monotonous than playing a two hole course?" I ask. "Playing a one hole course," replies my passenger. I have a hundred-odd duplicate or distance shot negatives of the races. If you're a photo-bug, write on your letterhead for one with my compliments.

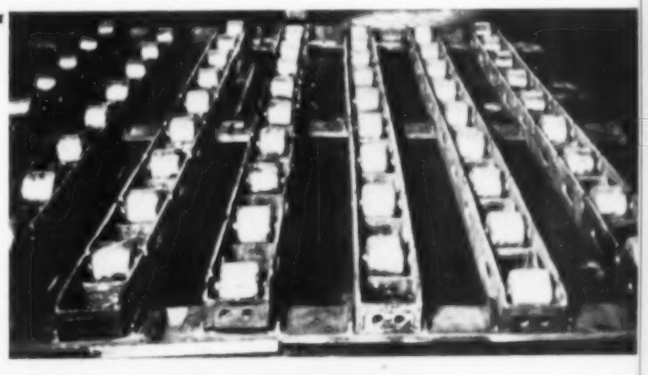
IF you're a production-hound, and breakdowns really hurt, better specify "General Alloys Castings" on any mechanical furnace you buy, and save the furnace builder from the temptation to "save" a few cents per lb. on inferior alloys. "NO FURNACE IS BETTER THAN ITS ALLOY WORKING PARTS." If you've read this far, this is good advertising.

SAVE SOMETHING ON CYANIDE AND HEAT POTS

THE roll flange pot with separate suspension flange gives minimum heat loss, freedom of expansion, lighter weight, longer life.

ROLLER RAILS

OVER 300 designs of roller rails have passed through General Alloys' engineering department. These shown are hollow. Many are in service from ten to fifteen years. Specify X-ite furnace parts and you won't hold anybody's bag.



GENERAL ALLOYS COMPANY

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DEST AND LARGEST EXCLUSIVE MANUFACTURER OF HEAT & CORROSION RESISTANT ALLOYS

You Can Insure Against Explosion

but . . .

THE FLAME-OTROL Prevents Explosion

Wherever a Gas Flame is used for Industrial Firing, the Flame-otrol is Designed to Instantly Shut-off the Gas in case of flame-failure.

The New Flame-otrol Bulletin No. 1101 is just off the Press. Illustrations, data, operating diagrams, prices, etc., are fully covered in its pages.

SEND FOR YOUR COPY NOW

SEE WHEELCO EXHIBIT . . ATLANTIC CITY . . BOOTH B84

WHEELCO INSTRUMENTS CO.
1929 SOUTH HALSTED STREET • CHICAGO

HYTEMPITE

For laying up fire brick with thin, long lasting, air-and-gas-tight joints of GREAT STRENGTH

Retains strength up to temperatures at which standard fire brick soften and fail . . . every joint equal strength—no pulling away . . . makes uniformly bonded walls—no cracks, no shrinkage . . . bonds all the way through joint . . . does not disintegrate or crumble out . . . air-sets at normal temperature . . . withstands sudden temperature changes . . . defies vibration of modern operations . . . has superior spreading qualities . . . easy to work . . . saves time and labor . . . cuts construction and maintenance costs.

Send for Bulletin MP 316

OTHER QUIGLEY PRODUCTS: SPECIFICATION FIRE BRICK INSULBRIX • INSULBLOX • INSULAG • INSULCRETE • Q-CHROMASTIC HEARTH-CRETE • Q-CHROME • CAST-REFRACT • TRIPLE-A PROTECTIVE COATINGS • Q-SEAL • DAMIT • ACID PROOF CEMENTS • ANNITE

QUIGLEY COMPANY, INC.
56 W. 45th Street, New York, N. Y.
Makers of HYTEMPITE, *"The World's Standard High Temperature Cement"*
Distributors with Stocks and Service in Important Industrial Centers throughout the United States, Canada, and in 32 other countries.
In Canada, Quigley Company of Canada, Limited, Lachine, P. Q.

Aluminum Alloys

(Starts on page 286)

Among technical improvements there is little to note except that the use of fluxes is much more common than it was, and that this and other improvements in melting and casting technique have made it possible to produce castings nearly free from gas and pinholes, although with increased shrinkage and sometimes cracking. The use of pressure die castings and gravity die castings is increasing with alloys specially suited to these processes, especially for die castings of improved dimensional accuracy.

There are few absolutely new applications of cast alloys; in the automobile industry the use of aluminum alloy cylinder heads is becoming more common in Great Britain and is perhaps the largest single advance, but alloy cylinder blocks are also being increasingly used, while cast, heat treated alloy wheels have also become a commercial proposition.

An interesting development which may have far-reaching consequences is that of the Cross engine; this has an aluminum piston working in an unlined aluminum cylinder. With a special type of piston ring the wear is said to be less than in a steel or iron cylinder with an aluminum piston. Aluminum alloy cylinder blocks would be more commonly used if a steel or iron liner were not required.

The use of aluminum pistons is now almost universal. Attempts are being made to develop aluminum alloy bearings, chiefly to save weight in airplane engines. Aluminum alloy connecting rods are being successfully used without bearing liners in engines in which they run on nitrided shafts.

Aluminum applications in architecture have been more concerned with wrought than cast alloys, but cast decorative panels, large grilles and column caps and bases have been made. Many of these are anodically treated and dyed and special alloys are required. Builders' hardware of aluminum has made some progress.

In the electrical field, cast aluminum clamps for overhead transmission lines are now used to a considerable extent, and large numbers of anti-vibration dampers employing aluminum castings. For both these uses alloys with a good corrosion resistance are necessary. Many parts for switchgear are made of aluminum alloys for non-magnetic properties and light weight.

In many industries, where moving parts which have to be frequently started and stopped are used, such as the textile industries, the light weight of aluminum alloys is proving useful. Aluminum molds for rubber goods are favored for their clean surface, light weight and thermal properties.

Two Highest *ratings:—*

The company that used this CHROMAX Lead Pot is rated by Dun's as

AAA-1

because of a high record of business performance.

The SERVICE of this Lead Pot with this company is

11,050 HOURS

of continuous operation, which entitles it to a Service Record of

AAA-1

PERFORMANCE is the one factor by which you can gauge satisfaction.

Satisfaction is assured when your heating equipment is made of Chromax or Nichrome, the Driver-Harris alloys.

DRIVER-HARRIS COMPANY

HARRISON, NEW JERSEY

for HEAT *and* CORROSION RESISTING ALLOYS

GUTHRIE • LEITZ
***Automatic* POLISHING MACHINE**

EASIER
•
FASTER
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MORE UNIFORM POLISHING

of
Microscopy
Specimen

THE Guthrie-Leitz Polishing Machine is of maximum usefulness to the metallurgist. Except for setting the specimens and changing the polishing discs, the work is entirely automatic. Specimens — and there can be several — are held to the disc with uniform pressure. Each specimen is rotated automatically and given an even polish to the edge. The user can prepare the specimens quickly and at the same time attend to other matters.

Special features are: several specimens polished at the same time; automatic rotating specimen holder magnet to provide uniform pressure; variable speed 350-1000 RPM without loss of power. Send for further details.

E. LEITZ, Inc.
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Damping Capacity

(Continued from page 262)

Not so long ago evidence of damping in the above sense (heat) was regarded as the first indication of the onset of fatigue damage. It was so easy to assume that every material could only dissipate a certain quantity of energy by internal damping, whereupon failure by fatigue would ensue. But for steel, at any rate, it has been positively proved that the capacity for dissipating energy in the form of heat by damping is unlimited. In other words, many steels are unharmed by cyclic plastic deformation (S_p) up to as high as 10% of the elastic (S_e). This is another way of saying that the endurance limit may be considerably above the elastic limit (if any).

Up to the present, practical engineers the whole world over have not troubled their heads about damping capacity. This indifference has militated against a wise discrimination in regard to the selection of material. In support of this statement, a few observations will be made.

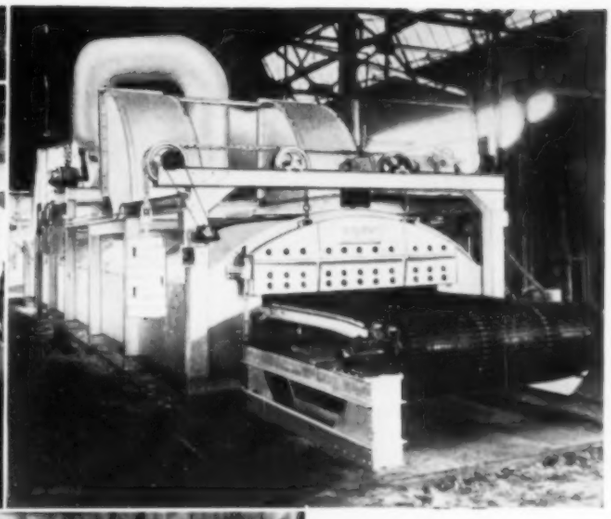
Theory, photo-elastic testing and experience all indicate that stresses are from two to five times the average at surface scratches or internal blemishes. Different materials differ greatly in their "degree of notch sensitivity" toward such unavoidable blemishes.

If a material is able to endure an indefinite number of cycles of alternating stress, and the corresponding cyclic strains are not purely elastic but include considerable components of plastic strain, this can be taken to indicate that its notch sensitivity is small. The effect of the plastic part of the cyclic strain is to render the stress concentration at discontinuities less severe than it would be if the cyclic strain was purely elastic, because the parts of the material which are most heavily stressed suffer particularly severe deformation. Thus, the effect of plastic strain is to lessen the intensity of a peak stress by spreading it over a wide area. On this account, the danger of starting a fatigue crack is diminished. But the greater the plastic strain, the greater is the damping capacity; hence damping capacity measures notch sensitivity, in the sense that if the damping capacity increases, the notch sensitivity falls off.

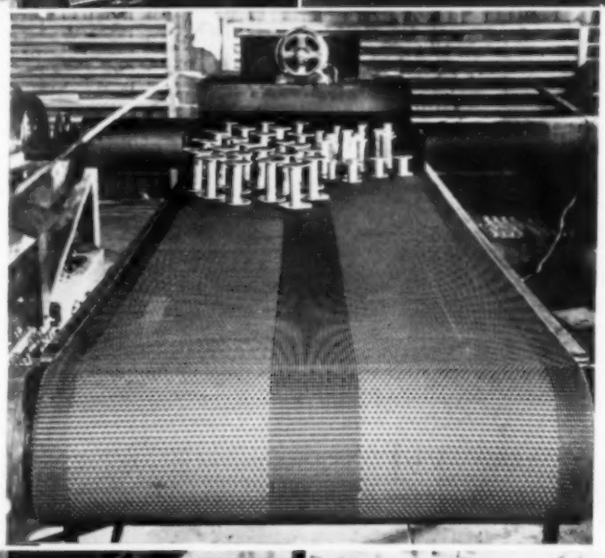
Certain items, like high voltage transmission lines, airplane wings and turbine blading, are thrown into dangerous vibration by resonance — a small force acting periodically in time with the natural period of vibration of the metallic part or assemblage. A material with high damping capacity will dissipate such energy as heat, and is thus a guarantee against high vibratory stresses. For instance, take failures in transmission lines: The

(Continued on page 302)

Above is shown Cambridge Interwoven belt conveying bottles through a glass annealing lehr.



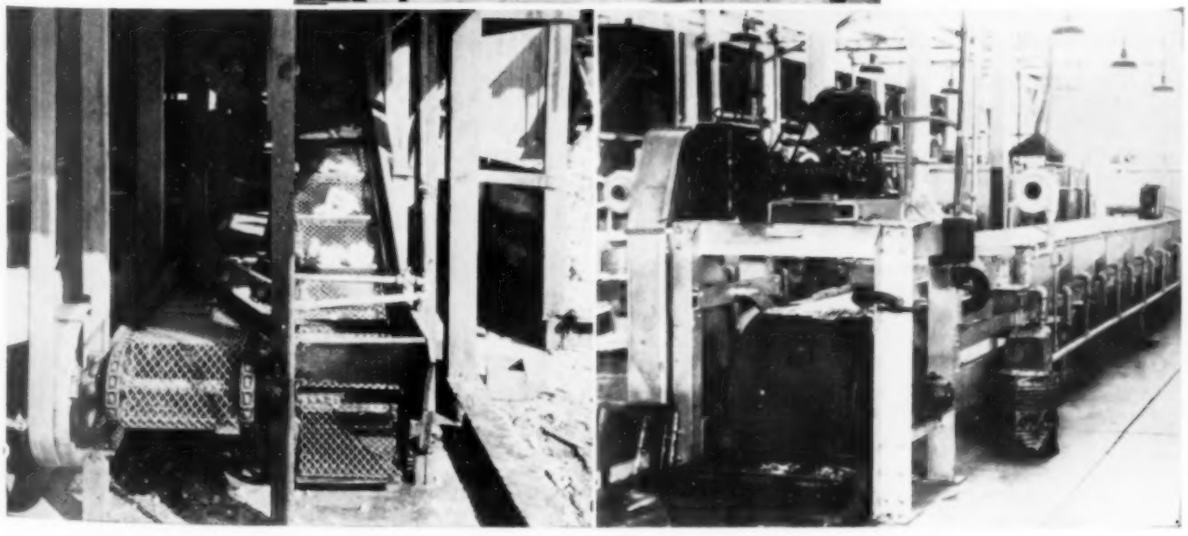
Above photo shows Cambridge Drive Chain Belting used in tempering railroad car springs.



Cambridge Belt installation with Duplex Selvage and Duplex Center conveying metal parts.

Below — Cambridge Spiral Wire Belt driven by means of a chain and sprocket drive and slatted for incline conveying of corn from the huskers.

Below—Duplex Selvage belt used in annealing silverware Blanks at 1500 degrees Fahrenheit.



The Cambridge Wire Cloth Company

Washington Street — Cambridge, Maryland

Boston — New York — Baltimore — Pittsburgh — Detroit — Chicago — San Francisco

Oil lines Texas pockets with over one and a quarter million dollars per day!

During the year 1936, Texas received for its 426,000,000 barrels of oil a total of $470,000,000; that figures out at more than one and a quarter million dollars of revenue for each day of the year. And it is a true revenue, for by the largest part of that money goes into Texas pockets—as wages, as lease and royalty payments, as taxes, for materials, supplies and services.

Production is the major oil activity in Texas. The state contains 50% of the proven oil reserves in the United States, and 53% of the new oil discovered in the United States during the past decade has been found in Texas. Last year, Texas' production was 40% of the total United States figure and 25% of world production; Texas produced slightly more oil in 1936 than the second and third ranking oil states combined.

If you are a manufacturer of the equipment and supplies the Texas oil industry uses, you have, then, an annual market of about a *quarter billion* dollars to shoot at. If you are a manufacturer of articles with a mass appeal, oil presents you with a market of about a million Texans jingling over $300,000,000 per year of wages, lease money and royalties in their pockets.

When all is said and done, however, oil is only the most important of the Texas resources which capture the interest of expanding or decentralizing industries. Texas boasts, in addition, salt, lime, cattle, cotton and cotton linters, sulphur, wool and mohair, vegetables, fruits, clays of various kinds, carbon black, timber, metallic and non-metallic ores. For fuel, there are inexhaustible supplies of natural gas.*

All these resources find their chief industrial utilization on the Texas coast. This area is served by first class rail, highway and water transportation facilities; it has a climate which is mild the year 'round; and it offers sound industrial enterprise a hearty cooperation.

Investigate the Texas coast country for your own company. We will gladly assist you: on request we will prepare for you, without cost or obligation, a comprehensive, reliable survey of South Texas, individualized to your company's particular needs. Your request for this service will be kept in strictest confidence. Address Houston Pipe Line Company, Petroleum Building, Houston, Texas.

HOUSTON PIPE LINE CO.
Subsidiary of Houston Oil Company of Texas
GEO. A. HILL, JR., President
Wholesalers of Natural GAS

*On our 650-mile system of natural gas pipe lines are located many manufacturers serving Texas giant oil industries.

Damping Capacity

(Starts on page 262)

strands of the cable may be made either of copper of high damping capacity or of light metal alloy possessing greater tensile and fatigue strengths than copper, but of greatly inferior damping qualities. In consequence, an equal wind agitates the copper cable far less than one made of light metal alloy. It is the latter which fails prematurely by fatigue, in spite of its superior fatigue strength.

The same thing applies with special force to the blades of airplane propellers, which are liable to vibrate violently at certain speeds of rotation. The amplitudes of vibration are great or small according to the material of which the blades are made. The endurance of the blades depends far more on the damping capacity of the material than on its fatigue strength.

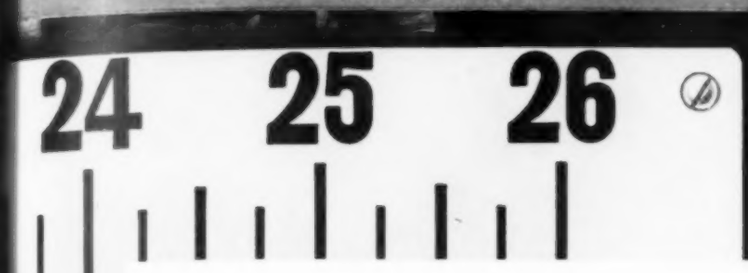
Finally the successful transition from forged crankshafts in gas engines to cast cranks has been due in considerable measure to the superior damping capacity of the latter.

Lastly, it is important to consider the effect of slightly loose joints in a vibrating structure (as riveted joints in a ship's hull, for instance) and how this structure would react if the joints were made rigid as by welding. Riveted joints introduce considerable damping, caused by the frictional resistance offered to slight relative movements between the overlapping plates, whereas in welded construction the welds do not develop any more damping than the internal damping of the steel itself. Hence, when exposed to equal disturbing influences, such as those set up by running machinery, a welded frame vibrates through a much greater amplitude than a riveted frame. The effect can be very troublesome; moreover, in such a complicated structure it is likely that there will be a whole series of critical speeds at which sympathetic vibrations will be stimulated in some part or other of the ship's hull.

In many cases, steel used in welded construction should therefore possess a high damping capacity. Unfortunately, there does not appear to be such a thing as a ductile steel which manifests considerable damping when the amplitude of vibration is small. But such a steel should not be ruled out as fundamentally unattainable; it is quite likely that in course of time it will be found. It would be invaluable in welded construction, as the low damping of the welds would be compensated for, even at low stresses, by the higher internal damping of the new material.

The ideal steel which needs striving for today is by no means the steel with the highest possible elastic limit, but, on the contrary, a steel with no truly elastic range, and which — like cast iron — exhibits some plastic strain at very low stresses.

MAXIMUM LEGIBILITY NUMERAL RECORDS



The desirability of recording several temperatures on one pyrometer chart is lost where the marks are poorly imprinted and over-printed, which results in a puzzling, undecipherable mass of blurs and blots.

No special skill is required to decipher the marks on a Brown Multiple-Recording Potentiometer Pyrometer chart record. Only one symbol—the + sign—is used and a number identifies the thermocouple from which the temperature recording is being made. Transparent, non-fading, colored inks further aid in rapid, legible reading of the individual records. Even where the numbers overlap, as shown on the opposite page, the records remain legible.

The Brown + symbol (an exclusive feature), in recording multiple-record temperatures is no mere arbitrary, ornamental dot. . . . it has definite, practical significance. The vertical line of the + represents temperature, while the horizontal line is the time coordinate . . . the intersection of the two represents an actual point on the time-temperature curve.

The wide 12-inch chart and the distinct imprint of the unique number print wheel makes it possible to simultaneously record and control from two to six temperatures from as many different thermocouples.

In the Brown Multiple-Recording Potentiometer Pyrometer, the combination of the steel numeral-print wheel with sharp, machine-cut numbers — specially heat-treated — and the vulcanized rubber, typewriter-type chart drum insures clear-cut recording.

Maximum legibility in reading the Brown Multiple-Record Potentiometer Pyrometer is further accomplished by a large, bold scale for long range sight reading. A narrow, finely divided scale — below the large scale — provides more accurate indication of the temperature being recorded.

There are many more refinements — each of real, practical value — fully explained in the Brown Potentiometer Catalog No. 1102 — write for it. THE BROWN INSTRUMENT COMPANY, *a division of Minneapolis-Honeywell Regulator Co.*, 4503 Wayne Avenue, Philadelphia, Pa. Offices in all principal cities. Toronto, Canada: 117 Peter Street — Amsterdam-C, Holland: Wijdesteeg 4 — London, England: 70 St. Thomas' Street, S.E.1.

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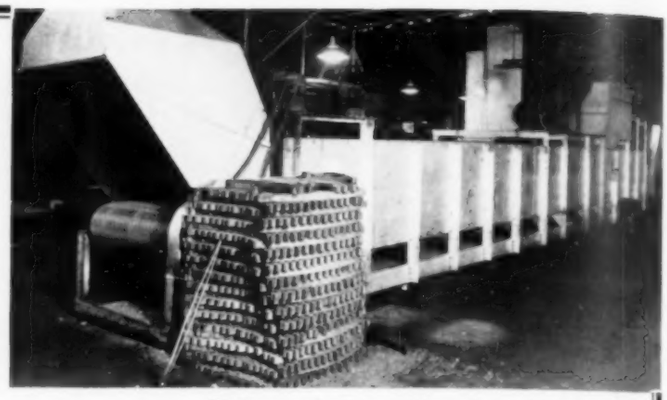

Discharge end of an 8000-pound per hour Circ-Air draw furnace, showing circulating fan and motor for driving it. Size: 4' wide by 40' long.

Many companies have installed Circ-Air units during 1937 and they are profiting by the many operating advantages of this equipment.

Circ-Air furnaces are being used for forging aluminum, heat treating aluminum, annealing brass, coloring brass, drawing all kinds of steel parts, etc. Because of patented method of passing hot gases through the work, heating time and temperature are controlled, regardless of any variation in loading of work on conveyors, up to maximum capacity. (Patent No. 1,860,887).

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Metal Yacht

(Continued from page 253) and rigging were a remarkable development of metal usage.

Here one may pause to recall an adventure which lead to a disaster, but a disaster that might have been far worse. On her maiden trip Ranger was out in a 20-mile north-wester that had raised quite a nasty run of sea. At night one of the upper shrouds parted, and soon the head of the mast was whipping about.

Presently other turnbuckles and gear began to give way under this increasing motion, and by three o'clock this immense hoist of mast, 150 ft. above the deck, was stripped of all support right down to the lowest pair of cross-trees. Still the mast held, though it whipped back and forth like a cane. But at last, due perhaps to metal fatigue, the great spar snapped, broken off just above the lower cross-trees.

Another mast was ordered by telephone. Though at the time it was thought that so big and yet so delicate a job would take six weeks, the work was completed in three, possibly a record, even for the 24-hr. schedule which had to be worked. It was a proud achievement for the Aluminum Co. of America and the Bath Iron Works.

The contrast revealed in the masts of the Ranger and Endeavour II is interesting. Unlike Endeavour II, which has a steel mast, the successful defender has a mast of strong aluminum alloy, of which the designer says that it is so resistant to corrosion that it can be, and is, left free of paint — something that one cannot chance with steel. Ranger's use of aluminum extends also to her two spinnaker booms, and her flexible boom is of the same metal. The challenger is more conservative, for her boom (of the broad "Park Avenue" type) is of steel, and her spinnaker boom is a hollow wooden spar.

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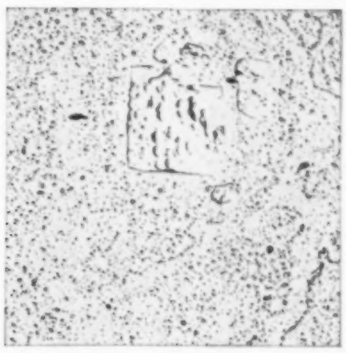

Zinc blende bright field taken with Neophot

Same specimen dark field taken with Neophot

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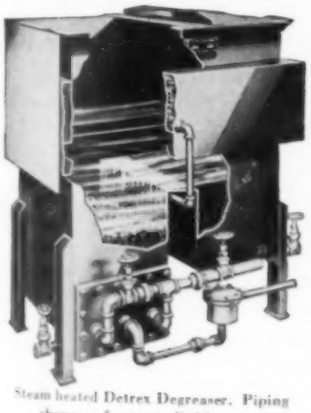

Steam heated Detrex Degreaser. Piping shown on front supplied by user

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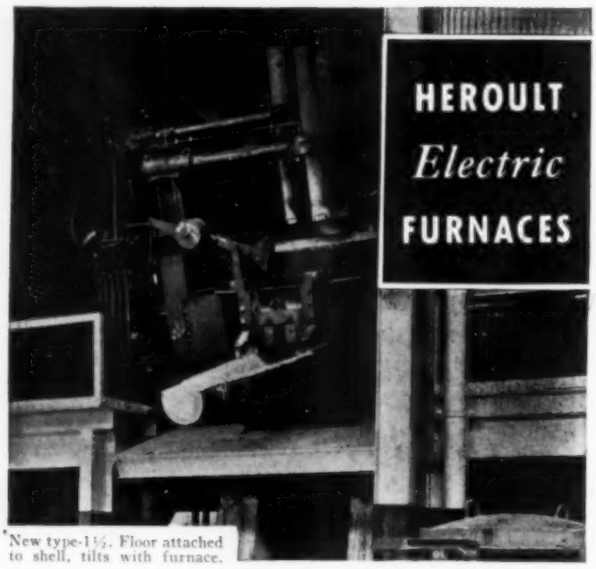

New type-1½. Floor attached to shell, tilts with furnace.

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UNITED STATES STEEL

Tin Coatings on Copper

(Continued from page 256)

appear to float up into the purer tin — a phenomenon frequently mentioned by other investigators. In comparison with the coatings produced on steel, which is the only other important metal that is coated with tin for industrial application, the contrast is marked, in that while the iron-tin compound grows with time in contact with molten tin it does not fragment and thereby influence the composition of the coating itself or of the molten tin bath. In the case of copper, the detached portions of compound proceed to dissolve to some extent in the pure tin, so that, on cooling, the number of particles of compound is increased by the crystallization of the tin-copper eutectic. This contamination of the tin by the copper was found to be related to the appearance of the coatings.

Coatings containing little copper (produced in a new bath) are particularly liable to ripples on the tin surface, and even to sizable bare patches.

When, however, coatings containing a small amount of copper were formed on a surface free from cuprous oxide inclusions, smooth coatings without any irregularity were obtained. Under identical conditions of tinning, effective quenching is essential to secure this result when working with ordinary copper containing Cu_2O inclusions.

Coatings containing more alloyed copper than the above consist of three classes: (1) Those containing considerable copper-tin eutectic; they are almost as irregular as those containing no copper at all. (2) Those containing also a little copper-tin compound throughout the coating; they give good coatings — in fact, deliberate additions of copper are frequently made to a tin bath in its initial stages of use. (3) Those containing considerably more copper than the eutectic composition; they have a very rough surface from crystals of compound which have grown to large size.

Practical Conclusions

The above implies that the percentage of copper in the bath should be just slightly above that in the eutectic composition. There is some doubt as to the actual composition of the eutectic, published figures varying from 0.75 to 1% copper. Practical experience indicates that with 1% copper in the bath smooth coatings are regularly obtained.

It would appear, therefore, that the temperature control of the tin bath should be very close, because porosity increases very rapidly with increase in dipping temperature and time. Since, in practice, the optimum composition of the bath is maintained by relying upon the copper-tin compound to sink, the bath should be heated from the top. Likewise stirring must be avoided.

METAL PROGRESS

1918 • ASM • 1937

TO MEMBERS AND FRIENDS,
American Society for Metals:

This particular issue of "Metal Progress" now in your hands, which we believe will bring a feeling of pride to every member of the American Society for Metals, is unusual in its informative content. It contains material to which you will refer many times in the future.

It serves to remind you that this month, during the week of October 18, the Nineteenth National Metal Congress and Exposition will be held at Atlantic City. Let me urge you to attend.

The American Society for Metals, with the cooperation of the American Welding Society, the Wire Association and the American Institute of Mining and Metallurgical Engineers, will present about one hundred forty-five technical papers, a selection from which will be of timely interest to any individual in the metal industry.

The most extensive presentation of commercial progress in the metal industry is offered by the two hundred fifty exhibits in the Exposition.

Almost everyone prefers seeing a play to reading the manuscript. By attending the Congress you may not only see this authentic drama of Metals in Industry but you are urged to participate if you wish. One of the major sources of advantage in attending lies in the personal contact with others with similar interests, glad to exchange experiences; the "corridor conclaves" are important.

It appears that records for quality and quantity may be broken at this year's meeting. Two lecture courses, one on Steel Making and one dealing with getting the most from the Microscopic Examination of Metal, are offered. A four-session Symposium on Carburizing, its principles and practice, will attract large attendance, while the Campbell Memorial Lecture will deal with carbon-free iron alloys nonetheless highly hardenable.

Papers, grouped by subjects, cover the up-to-the-minute thought on Heat Treatment, Fabrication, Testing at Ordinary and at High Temperature, Grain Size in Steel, Metallography, Research and Fundamental Principles, to mention a few ferrous and non-ferrous topics. A tremendous amount of painstaking work is represented by these valuable papers, merely listed on pages 324 to 326 of this issue.

We believe that the ultimate benefit to be derived from going to Atlantic City for the Congress and Exposition would compensate for even a very considerable effort to attend, and a cordial invitation is extended to all who are interested in the production or use of metals.

Edgar C. Bain
President

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				ROBERT S. ARCHER	1936

† Deceased

Errata, Page 323

Closing times for the National Metal Exposition are as follows:

Monday, Oct. 18	10:30 P.M.
Tuesday, Oct. 19	10:30 P.M.
Wednesday, Oct. 20 . .	10:30 P.M.
Friday, Oct. 22	7:00 P.M.

CONSOLIDATED PROGRAM

National Metal Congress

AMERICAN SOCIETY FOR METALS — AMERICAN WELDING SOCIETY
AMERICAN INSTITUTE OF MINING AND METALLURGICAL ENGINEERS
AMERICAN SOCIETY OF MECHANICAL ENGINEERS
WIRE ASSOCIATION

Sunday, Oct. 17, 1937

5:00 P.M. A.W.S.; President's Reception, Hotel Traymore

Monday, Oct. 18, 1937

9:30 A.M. A.W.S.; Business Meeting; Hotel Traymore
10:00 A.M. ⊜ Technical Session; Ambassador Hotel
12:00 M. National Metal Exposition opens; Auditorium
1:00 P.M. W.A.; Directors' Meeting, Program Committee Meeting; Ambassador Hotel
2:00 P.M. ⊜ Simultaneous Technical Sessions; Auditorium
2:00 P.M. A.W.S.; Industrial Research; Hotel Traymore
2:00 P.M. W.A.; Fatigue of Springs; Ambassador Hotel
4:30 P.M. ⊜ Lecture Course, Openhearth Steel Making; Auditorium
6:00 P.M. A.W.S.; Board of Directors' Meeting; Traymore
8:00 P.M. ⊜ Lecture Course, Metallographic Technique; Auditorium
8:00 P.M. A.I.M.E., ⊜, A.S.T.M., and A.I.P.; Round Table Discussion on Physics of Metals; Auditorium
10:00 P.M. National Metal Exposition closes

Tuesday, Oct. 19, 1937

9:30 A.M. A.W.S.; Session on Fundamental Research in Welding; Hotel Traymore
9:30 A.M. W.A.; Technical Session; Ambassador Hotel
10:00 A.M. ⊜ Technical Session; Auditorium
10:00 A.M. A.I.M.E.; Physics of Metals; Ritz-Carlton
12:00 M. National Metal Exposition opens; Auditorium
12:30 P.M. ⊜ Canadian Luncheon, Ambassador Hotel
2:00 P.M. ⊜ Technical Session; Auditorium
2:00 P.M. A.I.M.E.; Science Lecture; Ritz-Carlton Hotel
2:00 P.M. A.W.S.; Session on Fundamental Research in Welding; Hotel Traymore
2:00 P.M. A.W.S. and A.S.M.E.; Joint Session on Welded Fabrication; Hotel Traymore
2:00 P.M. W.A.; Technical Session; Ambassador Hotel
4:30 P.M. ⊜ Lecture Course, Openhearth Steel Making; Auditorium
7:30 P.M. A.W.S.; Conference and Meeting of Fundamental Research Committee; Hotel Traymore
8:00 P.M. ⊜ Lecture Course, Metallographic Technique; Auditorium
10:00 P.M. National Metal Exposition closes

Wednesday Morning, Oct. 20, 1937

9:30 A.M. A.W.S.; Fabrication Session; Hotel Traymore
9:30 A.M. W.A.; Ferrous Division Session; Ambassador
9:30 A.M. W.A.; Non-Ferrous Division Session; Ambassador
10:00 A.M. ⊜ Annual Meeting and Campbell Memorial Lecture; Ambassador Hotel
12:00 M. National Metal Exposition opens; Auditorium
12:15 P.M. A.I.M.E.; Iron and Steel Division, Executive Committee Luncheon Meeting; Ritz-Carlton Hotel
12:30 P.M. A.W.S.; Luncheon, Executives of Sections
12:30 P.M. Alumni Luncheons; Ambassador Hotel

Wednesday Afternoon, Oct. 20, 1937

2:00 P.M. ⊜ Technical Session; Auditorium
2:00 P.M. A.I.M.E.; Technical Session; Ritz-Carlton
2:00 P.M. W.A.; Ferrous Division; Ambassador Hotel
2:00 P.M. W.A.; Non-Ferrous Division; Ambassador
4:30 P.M. ⊜ Lecture Course, Openhearth Steel Making; Auditorium
4:30 P.M. W.A.; Annual Meeting; Ambassador Hotel
7:00 P.M. A.I.M.E. Institute of Metals and Iron and Steel Divisions and A.S.M.E. Machine Shop Practice Division; Dinner; Ritz-Carlton Hotel
7:30 P.M. W.A.; Annual Dinner and Stag Smoker; Ambassador Hotel
8:00 P.M. ⊜ Lecture Course, Metallographic Technique; Auditorium
10:00 P.M. National Metal Exposition closes

Thursday, Oct. 21, 1937

9:30 A.M. A.W.S.; Symposium on Welding of Alloy Steels; Traymore Hotel
10:00 A.M. ⊜ Carburizing Symposium; Ambassador
10:00 A.M. ⊜ Technical Session; Ambassador Hotel
10:00 A.M. A.I.M.E.; Iron and Steel Division, Technical Session; Ritz-Carlton Hotel
10:00 A.M. A.I.M.E.; Institute of Metals Division, Technical Session; Ritz-Carlton Hotel
10:00 A.M. W.A.; Technical Session; Ambassador Hotel
12:00 M. National Metal Exposition opens; Auditorium
12:15 P.M. A.I.M.E.; Institute of Metals Division, Executive Committee, Luncheon Meeting; Ritz-Carlton Hotel
12:15 P.M. A.I.M.E.; Openhearth Executive Committee, Luncheon Meeting; Ritz-Carlton Hotel
2:00 P.M. ⊜ Carburizing Symposium; Auditorium
2:00 P.M. ⊜ Technical Session; Auditorium
2:00 P.M. A.I.M.E.; Session on Openhearth Steel Practice; Ritz-Carlton Hotel
2:00 P.M. A.W.S.; Shipbuilding Session; Hotel Traymore
2:00 P.M. W.A.; Technical Session; Ambassador Hotel
4:30 P.M. ⊜ Lecture Course, Openhearth Steel Making; Auditorium
6:00 P.M. National Metal Exposition closes
7:00 P.M. ⊜ Annual Banquet; Ambassador Hotel
7:00 P.M. A.W.S.; Dinner Dance and Entertainment; Traymore

Friday, Oct. 22, 1937

9:30 A.M. National Metal Exposition opens; Auditorium
9:30 A.M. A.W.S.; Railroad Session; Hotel Traymore
10:00 A.M. ⊜ Carburizing Symposium; Auditorium
10:00 A.M. ⊜ Technical Session; Auditorium
2:00 P.M. ⊜ Carburizing Symposium; Auditorium
2:00 P.M. ⊜ Technical Session; Auditorium
4:30 P.M. ⊜ Lecture Course, Openhearth Steel Making; Auditorium
10:00 P.M. National Metal Exposition and the National Metal Congress ends

TECHNICAL MEETINGS

Monday

Morning

Something rather new in heat treatment is the process of **dry cyaniding.** R. J. Cowan and J. T. Bryce are prepared to give the "low-down" on it

Coercive force measurements are used to delve into the mechanism of steel hardening and tempering by R. S. Dean and C. Y. Clayton

An attempt by Austin and Norris to add to the meager literature on the subject of the effect of **tempering quenched hyper-euctectoid steel** produces some important results

Rupture Tests

P.M.: Two Simultaneous Sessions

T. G. Digges keeps the factor of austenitic grain size constant in determining the effect of carbon content on **hardenability** of high purity iron-carbon alloys

A new tool material falling in the class between high speed steel and the sintered carbides is a **cobalt steel** whose **precipitation hardening** treatment is described by R. H. Harrington

A quantitative estimate of **hardenability** can be obtained by a new, simple, and practical method reported by Burns, Moore and Archer

Opening the second simultaneous session, W. Mutchler and H. O. Willier tell about a rapid and inexpensive method for making **photomicrographs**

Pursuing investigations of the effect of temperature, time and partial pressure of oxygen on the scaling of carbon steel, Siebert and Upthegrove now tell what **grain size** has to do with **oxidation**

Carl Kinsley describes his balancing wave method of **magnetic testing** to determine structural changes in steel caused by heat treatment

Lectures at 4:30 and 8:00 P.M.

Earnshaw Cook starts a series of five lectures on **steel making** at 4:30 with a detailed historical sketch, and at 8:00 p.m. J. R. Vilella gives the first of three lectures on **metallographic technique** — it covers selection and preparation of specimens

Tuesday

Morning

In spite of the present trend toward **creep testing, long time rupture tests** also have an important place in evaluating high temperature properties of steels, as described by White, Clark and Wilson

Axel Hultgren comes all the way from Sweden to tell how they heat treat high speed steels in salt **baths** in that country

Short time high temperature tensile tests, which are currently receiving considerable attention, have also been investigated by University of Michigan's tireless team of White and Clark, assisted in this effort by C. J. Guarnieri, graduate student

Afternoon Session

Most of the work done on **austenitic grain size** concerns its effect on the properties of steel. Harry Tobin and R. L. Kenyon reverse this procedure and tell about the factors affecting the grain size itself

Derge, Kommel and Mehl of Carnegie Tech's Metals Research Laboratory present results of experiments supporting the hypothesis that **fine-grained steels** are the result of inhibition of grain growth by properly dispersed insoluble particles

Continuing on the subject of the mechanism underlying **grain growth,** a paper by Dorn and Harder postulates the existence of a grain growth inhibitor in aluminum-killed steels and discusses the effect of **pre-treatment**

Afternoon and Evening Lectures

The complicated and difficult subject of steel **refining** is covered in Earnshaw Cook's second lecture of the openhearth series held at 4:30

J. R. Vilella devotes an hour to **etching** of steel specimens in the metallographic technique series at 8 o'clock. New type of discussion will follow

TECHNICAL MEETINGS

Wednesday

Campbell Lecture in the Morning

A.S.M. members' annual opportunity to get together in one place for one big meeting — speeches (brief) from the new officers, reports of Society activities, and a reward for some deserving chapter

Then comes the highlight of the technical program — the Campbell Memorial Lecture. No Campbell lecturer has yet failed to live up to the honor, and that General Electric's W. P. Sykes will have something very much worth while is a foregone conclusion

Afternoon Session

Of practical importance to engineers engaged in designing power plant equipment for unusually high pressures and temperatures is a paper by Briggs and Gezelius on the effect of mass on the mechanical properties of **cast steel**

Cleaning or descaling before electroplating of steel may so alter the surface as to affect considerably the **fatigue resistance.** An investigation of this effect is given by J. H. Frye, Jr. and G. L. Kehl

U. S. Steel's Miller, Campbell, Aborn and Wright have found that carbon-molybdenum and chromium-molybdenum-silicon steels, when subjected to different **heat treatments,** likewise possess different **creep** properties

Afternoon and Evening Lectures

The next lesson in steel making concerns temperature control and pit practice. Be on hand at the Auditorium at 4:30 to hear it

Mr. Vilella winds up his course with a final lecture on microscopes and their manipulation. Excellent photomicrographs are shown by way of illustration

Low Resistance to Impact & Fatigue

Thursday

Morning

(*See next page for simultaneous carburizing symposium, a.m. and p.m., Thursday and Friday*)

New light is thrown on the **early stages of graphitization** (called by some investigators the incubation period) by Schwartz and Barnett

Using specimens of extreme purity, Sidney D. Smith's **X-ray study of A_3 points** confirms and extends the results of other investigations

X-Ray Studies Give Information About Meta

More investigation of the controversial subject of **graphitization,** by Cyril Wells, leads to a more accurate determination of the iron-graphite diagram in the region of the eutectoid transformation

Afternoon Session

Non-ferrous interests are not neglected — G. R. Dean and W. P. Davey have studied a copper-zinc alloy to determine the **solubility of copper** in the grain boundary material of the solid solution

D. W. Murphy, W. P. Wood and R. Girardi show that studies of **austenite transformation** in cast iron yield considerable information clarifying the hardening process and physical properties

How **columbium** and other additions help solve the problem of low toughness developed in fabrication and use of the popular and useful 5% **chromium steels** is told by Russell Franks

Afternoon Lecture at 4:30

Learn just what it takes to make a good ingot by attending Mr. Cook's fourth lecture on **ingot practice**

Annual Banquet

Everybody knocks off and even the Exposition closes at 6 so that no one need miss the annual banquet. Main attraction will be a good but brief speaker. Medals and honors are also awarded

TECHNICAL MEETINGS

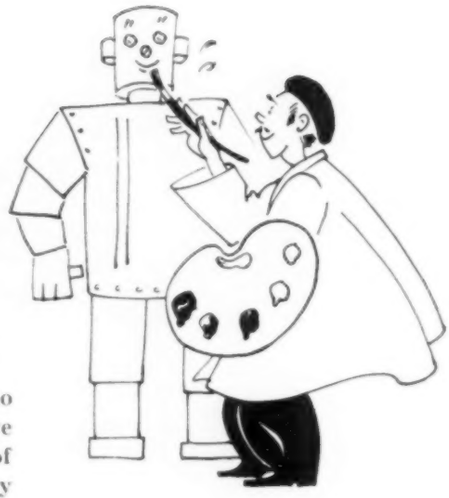
Friday

Morning

Springs and the name of F. P. Zimmerli are practically synonymous. W. P. Wood and G. D. Wilson are his co-authors of a paper on **valve spring wire**

Erich Fetz announces further results of his experiments on work hardening. His paper has to do with the recovery of **cold-worked nickel** on annealing

What with modern propensities to use metals in all sorts of decorative ways, C. B. F. Young's subject of **metal coloring** should be timely



Coloring

Afternoon

Two Timken authors, W. A. Hare and Gilbert Soler, report some new research on deoxidation type **inclusions** in alloy steels

In spite of the mushroom growth and widespread use of the continuous sheet mill, the **non-continuous mill** still has a place in industry, according to M. L. Samuels and Alfred Boyles

No program would be complete without a paper on **machinability.** D. E. Roda discusses the relation of size of spheroids to machinability and to holding edge of cutter

Lecture

"Process Metallurgy" is the intriguing title of the last lecture in the series on steel making. But don't wait for this lecture to hear Mr. Cook. You'll be sorry if you miss the first four!

Edge of Cutter

Symposium on Carburizing

Introductory

Heat treating expert Marc Grossmann starts the Carburizing Symposium out right with a **review of fundamentals** . . . H. W. McQuaid then discusses **solid carburizing agents** in a theoretical manner, and Gordon Williams follows with an introductory paper on **gas carburizing** which classifies the various gases used according to the type of case and applications desired

Special Aspects

Specialization starts Thursday afternoon when General Motors' Boegehold and Tobin discuss the selection of the proper type of **carburized case** — referring, of course, to automotive parts

The old bugaboo of **decarburization** is John A. Webber's subject. He includes a broad and helpful interpretation of results of past investigations

O. W. McMullan has a general discussion of **steels for carburizing** . . . . Jominy and Boegehold describe a **hardenability test** that grades steels of various compositions and grain sizes

Practical Considerations

First paper Friday morning is a historical account of **production carburizing** by E. F. Davis . . . . R. W. Roush and A. C. Dames have something to say about commercial **carburizing containers** . . . . S. L. Widrig discusses modern **solid carburizing compounds**

The last session of the symposium opens with a paper by Gable and Rowland on **commercial gas carburizing** . . . . Gas carburizing is also the subject of V. T. Malcolm, who talks about **light cases** . . . . B. B. Beckwith of Chrysler Corp. presents a final paper on **liquid bath carburizing**

A Good Liquid Bath

NATIONAL METAL EXPOSITION

Alphabetical list of EXHIBITORS

Air Reduction Sales Co., Booth E-62. Welding and cutting torches, brazing and hard facing apparatus.

Ajax Electric Co., Inc., Booth D-37. Electric heat treating furnaces.

Ajax Electrothermic Corp., Booth D-37. High frequency furnaces.

Allegheny Steel Co., Booth C-47. Stainless steels, sheets, bars, plates, strip, tubing, wire, rivets.

Edgar Allen Steel Co., Inc., Booth H-12. Tools and die steels.

Alox Corp., Booth G-11. Rust preventatives.

Aluminum Co. of America, Booth G-4. Aluminum alloys.

American Brass Co., Booth G-47. Copper alloys.

American Bridge Co., Booth—stage. (See United States Steel Corp.)

American Car & Foundry Co., Booth G-15. Electric bar heaters, forging heaters, rivet heaters.

American Chain & Cable Co., Booth A-32. Nibbling machines, die sets, welding wire.

American Coach & Body Co., Booth A-73. Spot welders.

American Cyanamid & Chemical Corp., Booth G-79. Case hardening compounds, chemicals.

American Electric Furnace Co., Booth C-39. Electric furnaces.

American Foundry Equipment Co., Booth B-40. Cleaning and descaling equipment.

American Gas Association, Gas Section. Gas equipment.

American Gas Furnace Co., Gas Section. Heat treating furnaces.

American Institute of Mining and Metallurgical Engineers, Booth A-80. Educational exhibit.

American Machine & Metals, Inc., Riehle Division, Booth F-8. Hardness testing machines.

American Machinist, Booth G-1. Publications.

American Metal Market, Booth G-70. Publications.

American Rolling Mill Co., Booth E-40. Stainless steels, enameling iron, sheets and plates.

American Sheet & Tin Plate Co., Booth—stage. (See United States Steel Corp.)

American Society for Metals, Booth H-85. Educational exhibit.

American Steel & Wire Co., Booth—stage. (See United States Steel Corp.)

American Welding Society, Booth C-3. Educational exhibit.

Ampco Metal, Inc., Booth H-2. High strength non-ferrous alloys.

Anderson & Sons, Booth G-2. Etched and lithographed metal products.

Arcos Corporation, Booth B-2. Welding accessories.

Armstrong Cork Products Co., Booth G-46. Insulating materials.

Atlas Fence Co., Booth H-45. Industrial fences.

Audubon Wire Cloth Corp., Booth H-45. Mesh, space and flexible wire cloth for industrial applications.

Automatic Gasflux, Inc., Booth A-78. Fluxes automatically fed into gas line for welding operations.

Automatic Temperature Control Co., Inc., Booth B-65. Temperature control systems, control valves for air, gas, water, oil and steam.

Babcock & Wilcox Co., Booth B-14. Refractories.

Baldwin-Southwark Corp., Booth F-44. Testing machines.

Barrett-Cravens Co., Booth A-10. Industrial trucks.

Bastian-Blessing Co., Booth A-23. Gas welding and cutting equipment.

Bausch & Lomb Optical Co., Booth H-64. Optical instruments for metallography and spectrography.

Bellis Heat Treating Co., Booth A-2. Heat treating salts and furnaces.

Bethlehem Steel Co., Booth D-66. Carbon and alloy steels.

G. S. Blakeslee & Co., Booth A-66. Cleaning and degreasing machines.

Botfield Refractories Co., Booth B-69. Refractories.

Bristol Co., Booth G-66. Pyrometers, temperature control equipment.

Brown Instrument Co., Booth B-75. Indicating and recording instruments, automatic control equipment.

Adolph I. Buehler, Booth B-17. Metallographic equipment.

Burdett Mfg. Co., Gas Section. Gas burning equipment.

Andrew C. Campbell Div., American Chain & Cable Co., Booth A-32. Nibbling machines, die sets, welding wire.

Carboloy Co., Inc., Booth F-48. Cemented carbide tools.

Carborundum Co., Booth H-24. Abrasives, grinding and cutting wheels, refractory products.

Carnegie-Illinois Steel Corp., Booth—stage. (See United States Steel Corp.)

Chapman Valve Mfg. Co., Booth A-15. Chapmanizing process, steel valves.

Chilton Co., Booth H-68. Publications.

Climax Molybdenum Co., Booth C-15 Molybdenum steels and irons.

Colmonoy Co., Booth G-76. Hard facing materials, cutting tools.

Columbia Steel Co., Booth—stage. (See United States Steel Corp.)

Continental Machine Specialties, Booth B-18. Precision filing and sawing equipment.

Crown Rheostat & Supply Co., Booth F-92. Plating and polishing tools.

Crucible Steel Co. of America, Booth B-8. Tool steels.

Cyclone Fence Co., Booth—stage. (See U.S. Steel Corp.)

A. P. DeSanno & Son, Booth H-15. Abrasive cutting equipment.

Despatch Oven Co., Gas Section. Gas heat treating furnaces.

Detroit Rex Products Co., Booth H-35. Metal cleaning equipment.

Detroit Testing Machine Co., Booth H-39. Physical testing apparatus.

Henry Disston & Sons, Inc., Booth A-18. Saws, knives, files, steel and tools.

Joseph Dixon Crucible Co., Booth B-44. Stoppers, nozzles and sleeves.

Dow Chemical Co., Booth G-86. Magnesium alloy die castings, forgings, rolled sheet and plate, and extruded sections.

Driver-Harris Co., Booth F-84. Heat and corrosion resisting castings, carburizing boxes, and furnace parts.

E. I. duPont deNemours & Co., Grasselli Division, Booth C-10. Pickling inhibitors, fluxes, acids, chemicals for plating.

METAL EXPOSITION

Alphabetical list of EXHIBITORS

E. I. duPont deNemours & Co., R. & H. Chemicals Dept., Booth F-14. Heat treating salts, sodium, plating chemicals, metal cleaners.

Eclipse Fuel Engineering Co., Gas Section. Heat treating furnaces and equipment.

Eisler Engineering Co., Booth G-71. Welding machines.

Electric Furnace Co., Booth D-80. Heat treating furnaces.

Electric Refractories Co., Booth H-8. Refractories.

Electro Alloys Co., Booth C-20. Heat and corrosion resisting alloys.

Electro Metallurgical Co., Booth H-52. Alloy steels and cast irons.

Elevator Supplies Co., Booth F-2. Wire drawing machines.

Ensign-Reynolds, Inc., Gas Section. Soft metal melting furnaces, soldering furnaces, burners, gas compressors, air blowers.

Firth-Sterling Steel Co., Booth F-68. Carbide tools, stainless steel products, wear resisting parts.

Florence Pipe Foundry & Machine Co., Booth H-41. Meehanite (high-test iron) castings.

J. B. Ford Sales Co., Booth G-43. Metal cleaners, burnishing compounds.

Foxboro Co., Booth G-36. Measurement and control instruments.

Gas Machinery Co., Gas Section. Forging furnaces.

Gehnrich & Gehnrich, Gas Section. Ovens, dryers, air heaters.

General Alloys Co., Booth E-10. Heat and corrosion resisting alloys, furnace parts.

General Electric Co., Booth A-33. Electric furnaces, atmosphere controls and welding machines.

General Electric X-Ray Corp., Booth A-33. X-ray testing equipment.

Globar Division, Carborundum Co., Booth H-24. High temperature heating elements.

Grob Brothers, Booth G-75. Die making equipment, saws, filing machines, brazing devices.

Halcomb Steel Co., Booth B-8. Tool steels and alloy steels.

Handy & Harman, Booth B-35. Brazing alloys and silver solders.

Harnischfeger Corp., Booth C-1. Electric welding equipment and motors.

Hauck Manufacturing Co., Booth A-75. Oil and gas burners, regulating valves.

C. I. Hayes, Inc., Booth B-41. Heat treating furnaces.

Haynes-Stellite Co., Booth H-52. Cutting tools, corrosion resistant castings.

Heat Treating & Forging, Booth A-70. Publications.

Heller Brothers Co., Booth L-3. Small tools.

Heppenstall Co., Booth B-1. Shear blades.

Hevi Duty Electric Co., Booth F-41. Electric heat treating equipment.

Hobart Brothers Co., Booth C-38. Electric arc welding equipment.

A. F. Holden Co., Booth B-32. Heat treating baths.

Hollup Corp., Booth A-62. Electric arc welders, electrodes and arc-welding equipment.

Charles A. Hones, Inc., Gas Section. Gas oven furnaces, melting furnaces, soft metal and soldering furnaces, industrial gas burners.

E. F. Houghton & Co., Booth B-95. Carburizing compounds, heat treating salts, industrial lubricants, cutting oil, leather belting and packings.

Illinois Testing Laboratories, Inc., Booth B-83. Pyrometers, thermometers.

Industrial Publishing Co., Booth F-4. Publications.

Industrial Steel Casting Co., Booth C-01. Steel castings.

Industry & Welding, Booth F-4. Publications.

International Nickel Co., Inc., Booth E-75. Nickel and nickel alloys.

The Iron Age, Booth H-16. Publications.

Iron & Steel Publishing Co., Booth H-72. Publications.

Jessop Steel Co., Booth G-10. Tool steels and alloy steels.

Johns-Manville, Booth C-43. Insulating and refractory materials.

Jones & Laughlin Steel Corp., Booth E-32. Hot and cold rolled steel, tin plate.

C. M. Kemp Mfg. Co., Gas Section. Gas producers and premixers.

G. N. Krouse, Booth F-5. Fatigue testing machines.

Lebanon Steel Foundry, Booth B-15. Steel castings.

Leeds & Northrup Co., Booth F-61. Heat treating furnaces, pyrometers and controlling instruments.

E. Leitz, Inc., Booth G-14. Photomicrographic apparatus.

Lepel High Frequency Laboratories, Booth C-48.

Lewis Machine Co., Booth B-4. Wire drawing machinery.

Lincoln Electric Co., Booth C-32. Electric welding equipment and supplies.

Lindberg Engineering Co., Booth A-67. Heat treating equipment.

Linde Air Products Co., Booth H-32. Welding and cutting apparatus, welding gases.

Ludlum Steel Co., Booth G-85. Tool and alloy steels.

Maas and Waldstein Co., Booth A-6. Lacquers, enamels, synthetics, etc.

Machinery, Booth G-67. Publications.

Macklin Co., Booth B-45. Grinding wheels, cut-off machines.

Magnaflux Corp., Booth G-42. Inspection method and equipment.

Magnetic Analysis Corp., Booth G-63. Magnetic analysis equipment.

Mahr Manufacturing Co., Booth B-81. Oil and gas furnaces, burners.

Manganese Steel Forge Co., Booth H-45. Manganese steel wire cloth, screens, forgings, welding wire.

Manhattan Rubber Mfg. Co., Booth G-35. Abrasive cut-off and finishing wheels.

Marburg Brothers, Inc., Booth G-6. Cutting tools, gages, pneumatic hammers.

Maurath, Inc., Booth A-50. Welding electrodes.

McKay Company, Booth H-81. Welding electrodes.

Metal Industry Publishing Co., Booth H-79. Publications.

Metals & Alloys, Booth L-1. Publications.

Metal & Thermit Corp., Booth F-22. Welding electrodes and equipment.

Metal Progress, Booth H-85. Publications and educational exhibit.

Metals Coating Co. of America, Booth E-62. Sprayed metal coating equipment.

Metlab Co., Booth D-17. Demonstration of heat treatment of metals.

Michigan Steel Casting Co., Booth F-49 and G-39. Heat and corrosion resisting castings.

A. Milne & Co., Booth H-12. Tool and die steels.

Minneapolis-Honeywell Regulator Co., Booth B-75. (See Brown Instrument Co.)

Modern Machine Shop, Booth H-8[illegible] Publications.

METAL EXPOSITION

Alphabetical list of EXHIBITORS

Molybdenum Corp. of America, Booth C-35. Molybdenum and tungsten alloys.

Morrison Engineering Co., Booth C-83. Equipment for wire mills.

Mullite Refractories Co., Booth B-3. Refractories.

National Carbide Corp., Booth E-62. Carbide.

National Cylinder Gas Co., Booth B-22. Oxy-acetylene cutting machines.

National Gas Furnace Co., Booth A-72. Heat treating furnaces.

National Industrial Publishing Co., Booth A-76. Publications.

National Tube Co., Booth—stage. Tubing.

New Jersey Zinc Sales Co., Booth F-32. Zinc alloys, die castings

Norton Company, Booth A-1. Grinding wheels, refractories.

Ohio Crankshaft Co., Booth L-8. Automatically hardened crankshafts.

Tinius Olsen Testing Machine Co., Booth C-18. Testing machines.

Owen Electric Sales Co., Booth C-4. Welding machines.

Page Steel & Wire Div., American Chain & Cable Co., Booth A-32. Welding wire, miscellaneous wire.

Pangborn Corporation, Booth A-81. Blast cleaning and dust collecting equipment.

Paramount Oilless Bearing Co., Booth H-75. Oilless wood bearings and bushings, elevator guides, wood turnings.

Park Chemical Co., Booth H-84. Heat treating materials, buffing and polishing materials.

Parker-Kalon Corp., Booth B-21. Screws and fastening devices, measuring instruments, gage blocks.

Partlow Corp., Gas Section. Temperature controls, gas valves, safety pilots.

Henry Pels & Co., Booth F-3. Cutting and fabricating machines.

George F. Pettinos, Inc., Booth A-14. Sands, gravels, insulating cements, graphites, foundry facings, etc.

Philadelphia Drying Machinery Co., Booth B-85. Heating furnaces, oil burners, gas burners.

Horace T. Potts Co., Booth G-72. Iron and steel.

Product Engineering, Booth G-1. Publications.

Production Machine Co., Booth F-80. Polishing, finishing and buffing machines.

Pyle-National Co., Booth H-44. Airplane and airport lighting equipment, locomotive headlights, generating sets, etc.

Pyrometer Instrument Co., Booth E-17. Radiation, immersion, optical and surface contact pyrometers.

Products Finishing, Booth H-69. Publications.

Quigley Co., Inc., Booth E-2. Refractories.

Republic Steel Corp., Booth D-32. Alloy and stainless steels, sheets, bolts and nuts, pig iron, etc.

Riehle Division, American Machine & Metals, Inc., Booth F-8. Hardness testing machines.

Riverside Metal Co., Booth F-10. Non-ferrous alloys.

Stanley P. Rockwell Co., Inc., Booth H-71. Heat treating equipment.

John A. Roebling's Sons Co., Booth A-11. Wire rope and miscellaneous wire.

Rustless Iron & Steel Corp., Booth A-22. Rustless and stainless steels and irons.

Joseph T. Ryerson & Son, Inc., Booth B-9. Steel and allied products.

Safety Gas Lighter Co., Booth B-36. Gas lighters, gas ranges, hot water heaters.

George Scherr Co., Inc., Booth D-76. Optical instruments and testing machines.

Scully Steel Products Co., Booth—stage. (See United States Steel Corp.)

Selas Co., Gas Section. Gas premixers, burners, soldering systems.

Sentry Co., Booth F-1. Hardening furnaces, high temperature tube furnaces.

Seymour Mfg. Co., Booth F-92. Nickel silver, phosphor bronze, sheets, blanks, wire, rods, shells, etc.

Shakeproof Lock Washer Co., Booth D-10. Lock washers.

Shenango-Penn Mold Co., Booth D-83. Centrifugally cast bronze and bronze products.

Sleeper & Hartley, Inc., Booth H-65. Wire and spring making machinery.

Spencer Turbine Co., Booth B-71. Turbo compressors, vacuum cleaners.

Steel, Booth L-2. Publications.

Steel City Testing Laboratory, Booth F-18. Testing machines.

Stoody Co., Booth H-88. Hard facing materials, cutting tools.

D. A. Stuart & Co., Booth B-44. Industrial oils and greases.

Surface Combustion Corp., Gas Section. Heat treating furnaces, burners, accessories.

Syncro Machine Co., Booth F-2. Wire machinery.

C. J. Tagliabue Mfg. Co., Booth B-41. Indicating, recording and controlling pyrometers.

Taylor Hall Welding Corp., Booth H-75. Welding machines.

Tennessee Coal, Iron and Railway Co., Booth —stage. (See United States Steel Corp.)

Thermal Products Corp., Booth G-17. Insulating materials.

Timken Roller Bearing Co., Booth E-48. Alloy steels in bar and tube form.

Titanium Alloy Mfg. Co., Booth F-76. Titanium alloys and compounds.

Torrington Mfg. Co., Booth H-65. Wire manufacturing machines.

Una Welding, Inc., Booth G-22. Welding machines.

Union Carbide and Carbon Corp., Booth H-52. Welding and cutting equipment, ferro-alloys, heat and corrosion resisting alloys.

Unitcast Corp., Booth C-91. Steel castings.

United States Steel Corp., Booth—stage. Alloy steels, high tensile steels, stainless steels.

Universal-Cyclops Steel Corp., Booth H-84. Tool steels, stainless and specialty steels.

Vanadium-Alloys Steel Co., Booth G-32. Vanadium steel, tool steels.

Vanadium Corp. of America, Booth H-20. Vanadium alloys and compounds.

Victor Saw Works, Inc., Booth B-39. Hacksaw blades and machines.

Welding Engineer, Booth A-42. Publications.

Wells Mfg. Corp., Booth H-21. Metal cutting saws.

Westinghouse Electric & Mfg. Co., Booth E-19. Welding equipment and electric furnaces.

Wheelco Instruments Co., Booth B-84. Temperature control instruments.

Wiedemann Machine Co., Booth A-46. Turret punches.

H. A. Wilson Co., Booth B-7. Platinum alloys, precious metals, thermostatic metals.

Wilson Mechanical Instrument Co., Booth C-50. Rockwell hardness testers.

Wilson Welder & Metals Co., Booth E-62. Electric welding machines.

Wire Association, Booth A-40. Educational exhibit.

Youngstown Sheet & Tube Co., Booth A-63. Alloy steels.

Carl Zeiss, Inc., Booth G-80. Microscopes and accessories

Personals

First recipient of the newly created Cultural Order of the Rising Sun (Japanese parallel of the Nobel Prize): **Kotaro Honda** ⊜, president, Tohoku Imperial University, Sendai, Japan.

John F. Robb ⊜ has been transferred from the Canton to the Pittsburgh office of the Climax Molybdenum Co.

To organize a welding department and to teach arc and acetylene welding **Everett G. Smith** ⊜ has left the Beaver Dam, Wis., Vocational School and joined University of Louisiana.

Arnold P. Hoelscher ⊜, formerly assistant professor of metallurgy, Purdue University, is now research associate for Carnegie-Illinois Steel Corp., Pittsburgh.

Booth B-48 National Metal Exposition
Atlantic City *October 18-22, 1937*
STEP IN AND ASK FOR YOUR FREE SOUVENIR

Edward P. Geary ⊜ has left the employ of the Vanadium-Alloys Steel Co. and Colonial Steel Co. and is now mid-western sales manager for Rustless Iron & Steel Corp.

Granted honorary membership in the American Society for Testing Materials in recognition of their achievements in the field of engineering materials: **John A. Capp**, chief of the Testing Laboratory of the General Electric Co., and **G. H. Clamer** ⊜, president and general manager of the Ajax Metal Co.

Alexander Gobus has joined the metallurgical staff of Lucius Pitkin, Inc., New York.

A. J. Langhammer has been made president of Amplex Division of Chrysler Corp.

Selected by the American Foundrymen's Association to present the exchange paper before the 1938 meeting of the Institute of British Foundrymen: **James T. MacKenzie** ⊜, chief metallurgist, The American Cast Iron Pipe Co.

George P. Burks ⊜ has been appointed chief chemist for the blast furnaces, openhearth and rolling mills at the Gary Works of the Carnegie-Illinois Steel Corp.

Formerly radiographer for A. O. Smith Corp., **Armand G. L. Barkow** ⊜ is now metallurgical engineer with the Maryland Casualty Co.

Appointed secretary of Fischer & Porter Co: **Howard W. Gripton** ⊜, formerly engineering manager of Schutte & Koerting Co., Meter Department.

Transferred to the Pacific Coast Division, Aluminum Co. of America, Oakland, Calif.: **Howard J. Heath** ⊜, assistant foundry metallurgist.

William F. Boudreau ⊜ is now in a training course at the Middletown plant of the American Rolling Mill Co.

An invitation

TO INSPECT A DISPLAY OF

ALLOY STEEL CASTINGS

COVERING A BROAD FIELD OF INDUSTRY

BOOTH No. C-91

THIS SIGNATURE IDENTIFIES TOLEDO ALLOY CASTINGS

UNITCAST CORPORATION

TOLEDO, OHIO

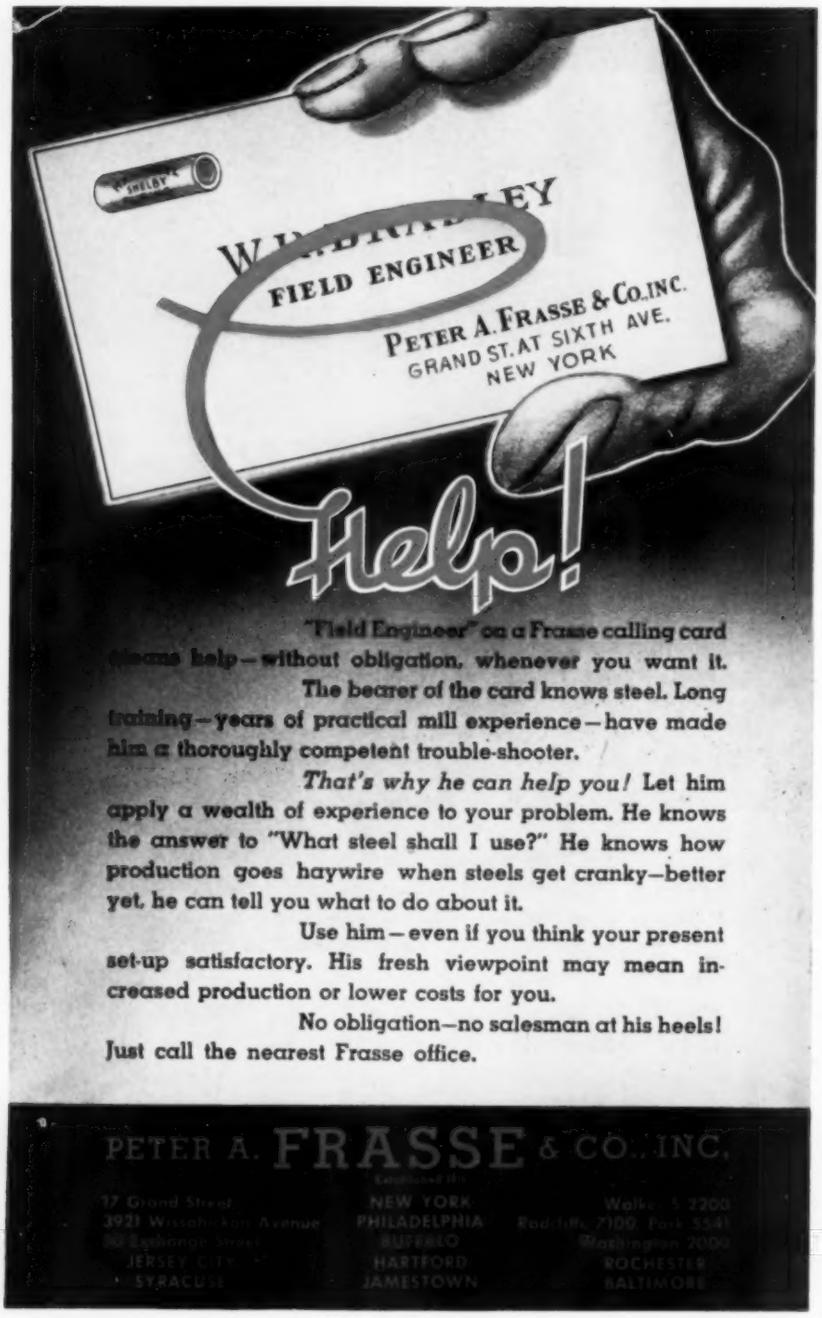
Personals

Ernest H. Wyche, formerly metallographist for Rustless Iron & Steel Co., is now in the research laboratory of United States Steel Corp.

Assigned to the Lackawanna Plant of the Bethlehem Steel Co.: **Richard C. Young**, at present undergoing a training course for the Openhearth Division.

Transferred from the United States Steel Corp. Research Laboratory to the Duquesne Works of Carnegie-Illinois Steel Corp. as general foreman of the Metallurgical Department: **Bernard R. Queneau**.

Appointed a member of the Research Staff of General Electric Co.: **L. P. Tarasov**, formerly at Massachusetts Institute of Technology.


SHELBY
FIELD ENGINEER
PETER A. FRASSE & CO. INC.
GRAND ST. AT SIXTH AVE.
NEW YORK
Help!
"Field Engineer" on a Frasse calling card means help—without obligation, whenever you want it.
The bearer of the card knows steel. Long training—years of practical mill experience—have made him a thoroughly competent trouble-shooter.
That's why he can help you! Let him apply a wealth of experience to your problem. He knows the answer to "What steel shall I use?" He knows how production goes haywire when steels get cranky—better yet, he can tell you what to do about it.
Use him—even if you think your present set-up satisfactory. His fresh viewpoint may mean increased production or lower costs for you.
No obligation—no salesman at his heels! Just call the nearest Frasse office.
PETER A. FRASSE & CO., INC.
NEW YORK
PHILADELPHIA
BUFFALO
HARTFORD
JAMESTOWN
ROCHESTER
BALTIMORE

Formerly repair officer on U.S.S. Dobbin, **W. N. Thornton** now has command of U.S.S. Simpson.

R. L. Schell has resigned as melter foreman at Edgewater Steel Co. to take charge of the openhearth and electric furnaces of National Malleable & Steel Castings Co., Sharon, Pa.

Harold J. Elmendorf is now employed at the United States Steel Corp. Research Laboratory.

Transferred to the Patent Department of Union Carbide & Carbon Research Laboratories as engineer: **Henry M. Chapin**, formerly in the Cylinder Maintenance & Testing Department of The Linde Air Products Co.

G. Herbert Bartow has severed his connections with Lucius Pitkin, Inc., and is now a member of the metallurgical staff of Crucible Steel Co. of America, Atha Works.

Associated with Toledo Woodhead Springs, Ltd., Toledo Steel Works, Sheffield, England: **Andrew C. Stenhouse**, formerly with Barnes - Gibson - Raymond, Detroit.

Maurice C. Fetzer is now assistant professor of metallurgy and metallography at Pennsylvania State College, School of Mineral Industries. He was formerly in the department of mining and metallurgy at Washington State College.

Robert C. Kintner has been appointed associate professor of chemical engineering at Armour Institute of Technology.

M. T. Davis, formerly with General Electric Co., Ontario, Calif., is now with Kanawha Mfg. Co., Charleston, West Va.

Selected to act as scientific advisor to a tribunal between United States and Canada for the settlement of a controversy concerning smelter fumes: **R. S. Dean**, chief engineer of the Metallurgical Division, U.S. Bureau of Mines.

Heat Treatment *and* Metallurgical Control

By O. N. Peterson
Plant Metallurgist
Buick Motor Division, General Motors Corp.
Flint, Mich.

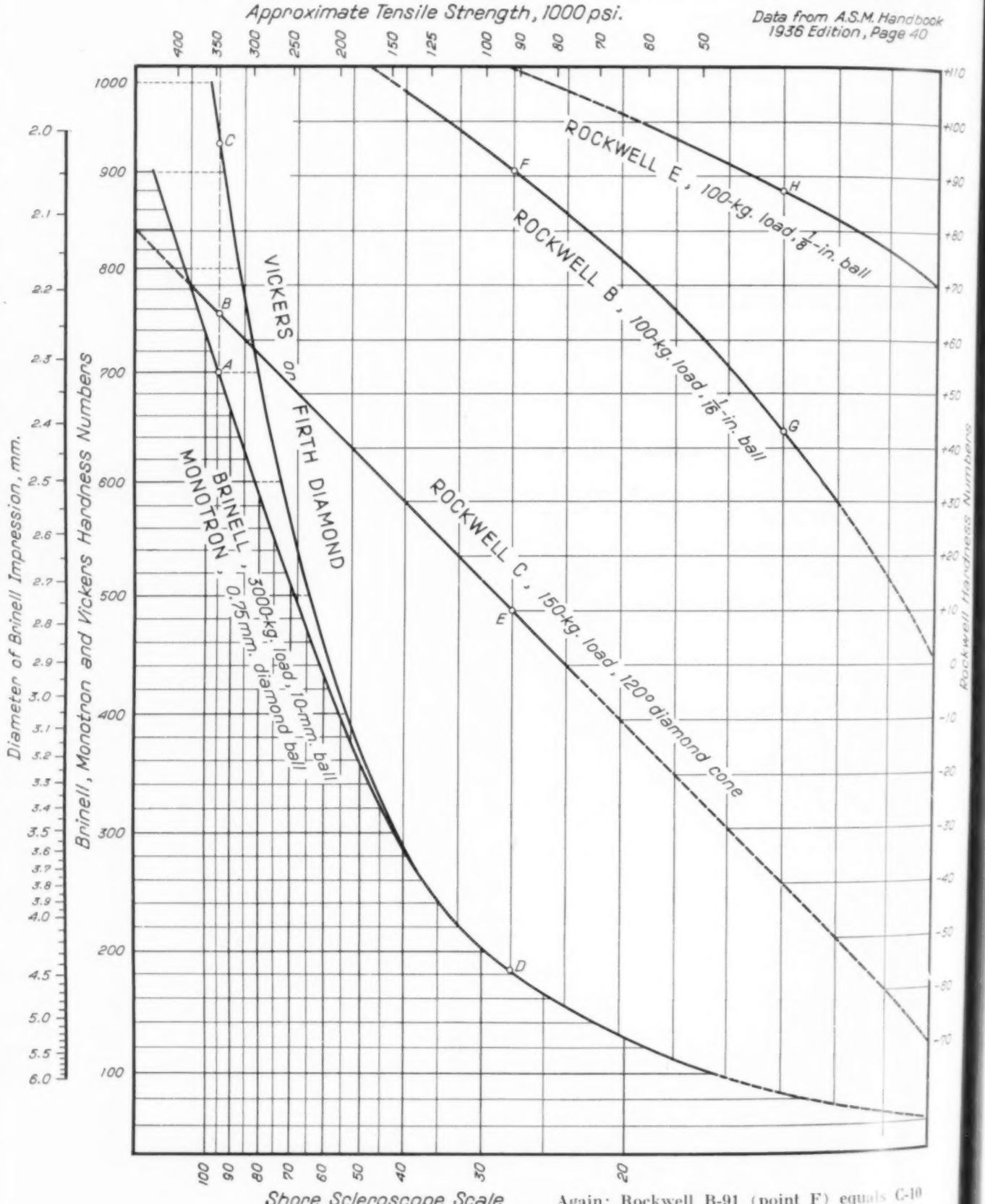
Machinability of Alloy Steel Parts — Such as the Automobile Main Shaft Shown in Process — Is a Prerequisite of the Raw Material in Mass Production Industries. All photos courtesy Buick Motor Division

TOO MUCH EMPHASIS cannot be placed on the importance of metallurgical control of automotive steel in this present age of car manufacturing. Automotive engineers are constantly increasing motor speeds and car performance, using the most severe testing conditions as a criterion of its safety and suitability for public use. At the same time, they are quite insistent in keeping weights relatively low in spite of stresses involved. Demands of the production department are such that the machine shop insists on the highest cutting speed at lowest possible tool and labor cost. Cost departments are also in for their share of criticism on the cost of raw materials; costs of machining operations are compared with those in other high production shops; periodically it is brought to light, with emphasis, that great economy rests in fabricating comparative parts in competitive shops.

All this involves, sooner or later, an attempt by the metallurgist toward more delicate metallurgical control and an incessant groping for something better, in order to satisfy the requirements and needs of each of the clamoring divisions which make up one compact manufacturing organization. Probably at no time has there been such an incentive for metallurgical staffs to introduce new developments and new products, and with the decidedly cooperative feeling that prevails between metallurgist, manufacturer and steel mill, a great many things should be accomplished. Interrelation of raw material, heat treatment, fabrication, and service properties requires adequate control at each step of the way between steel mill and completed automobile.

There are undoubtedly a great many ways to approach this matter of control of automotive steels, and they vary from shop to shop. The number and kind of tests necessary to maintain this control is quite dependent on the part — as was clearly pointed out by J. G. Gagnon in METAL PROGRESS last September. On transmission gear steels of the nickel-chromium type, (S.A.E. 3145) for instance, we find it very essential for good control of heat treating and also for maintaining desired physical properties, to hold the

Hardness Conversion Chart for Steels



Verticals represent equivalent hardness.

For instance: Brinell or Monotron 700 (point A) equals Rockwell C-65 (point B), equals Vickers 930 (point C), equals Scleroscope 94 (bottom scale), and about 340,000 psi. tensile (top scale).

Again: Rockwell B-91 (point F) equals C-10 (point E), equals Brinell, Monotron or Vickers 184 (point D) and Scleroscope 28, and has about 92,000 psi. tensile strength.

Finally, Rockwell B-43 (point G) equals E-87 (point H). Curve for latter scale is from Bureau of Standards Research Paper No. 185.

carbon to a five point range and nickel and chromium close to the mean analysis on the alloying elements, thus giving us our specification 3145-A. The range for the alloying elements in S.A.E. steels has always been quite wide — and perhaps in some steels is necessary — but in many cases, at least, it could be narrowed down and probably result in greater uniformity.

Grain Size Control

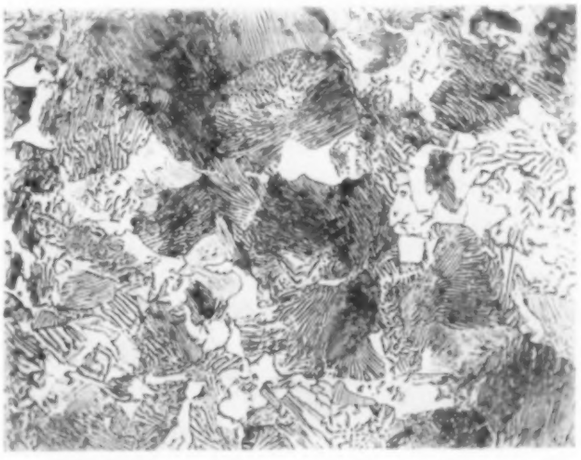
Fine-grained steel with grain size No. 6 to 8, as determined by the McQuaid-Ehn test, is used for Buick transmission gears because of its inherent and improved physical properties over coarse-grained steels. The steel mills seem to have such grain control well in hand on this type of material for they rarely miss, and usually hit a No. 7 grain size quite consistently. On a group of 30 heats received consecutively there were 26 with grain size No. 7 and four rated as 7½. Micro examinations for dirt in the rough bar stock determine the type, kind and abundance of inclusions in a given area; normality rating, banding, and general core conditions are all determined on a routine basis for every heat of transmission gear steel received.

We also find a deep etch test throws some light on the machinability to be expected. There are indications that fine-grained heats that have not been too thoroughly killed in the melting practice will machine better than those that have been thoroughly killed. In order to check this condition, a gear is forged from a new heat, annealed, cut longitudinally, ground on the cut surface, then etched for 45 min. in a 50% muriatic acid solution at a temperature of 160° F. On a heat not too thoroughly killed the machined and ground surface will be quite deeply attacked by the acid along the forging flow lines. A thoroughly killed heat, however, will be comparatively smooth, unattacked. A type and degree of etch pattern is selected and used as the standard of comparison. An explanation for the difference in etch of the two kinds of material is not quite clear, but from the information we have gathered so far, better machining seems to be associated with heats of steel that etch more deeply. In cutting there seems to be a tendency for the chip to break and free itself more readily from the cutting tool; feeds and speeds can be increased thereby, with correspondingly longer tool life.

Regulation of Annealing Cycle

Another phase of control in processing transmission gear steels, which not only has a bearing on the machinability but on hardenability as well, is the annealing cycle. The annealing cycle for Ni-Cr 3145-A specification is so selected that the final microstructure will have a coarse pearlite as the predominating constituent, with well distributed free ferrite along the grain boundaries and perhaps a slight tendency toward a few spheroids and divorced cementite. Brinell hardness should range from 197 to 207. This seems to give the best general structure and hardness for broaching, turning and hobbing of gears.

Any attempts to increase the amounts of spheroids or divorced cementite, which will usually bring the hardness down to 187 or softer, would be detrimental to good broaching and hobbing, but would probably favor turning. Slight increase in hardness higher than 207 borders on sorbitic structures with poor turning properties and fair hobbing and broaching. As the carbon content increases from 0.45 up to 0.50%, it is quite favorable to have greater amounts of spheroids and divorced cementite (with no apparent detriment to machinability).



Annealed 3145-A for TransmissionGears. Nital etch, 500 dia. Desirable structure to satisfy general machining conditions, which means turning, hobbing, broaching, sharing

To achieve the desired ends an annealing cycle is used which is completed in nine hours in a four-zone furnace having a capacity of 1250 lb. per hr. The settings in the four zones are as follows: Zone No. 1, 1600° F.; zone No. 2, 1600° F.; zone No. 3, 1275° F.; zone No. 4, 1200°

F. Annealing temperatures as high as 1850° F. have been tried on this steel but were found to be more of a detriment than a help to machinability. Temperatures as low as 1450° F. have also been tried with equally poor results. The high temperatures in the initial zone were tried with the idea of coarsening the grain size, which they did, but at the same time stabilized the austenite so strongly that something more than nine hours in the furnace's cooler zones was required to break it down to the softer machining constituent. In addition to that, furnace life would have been greatly shortened.

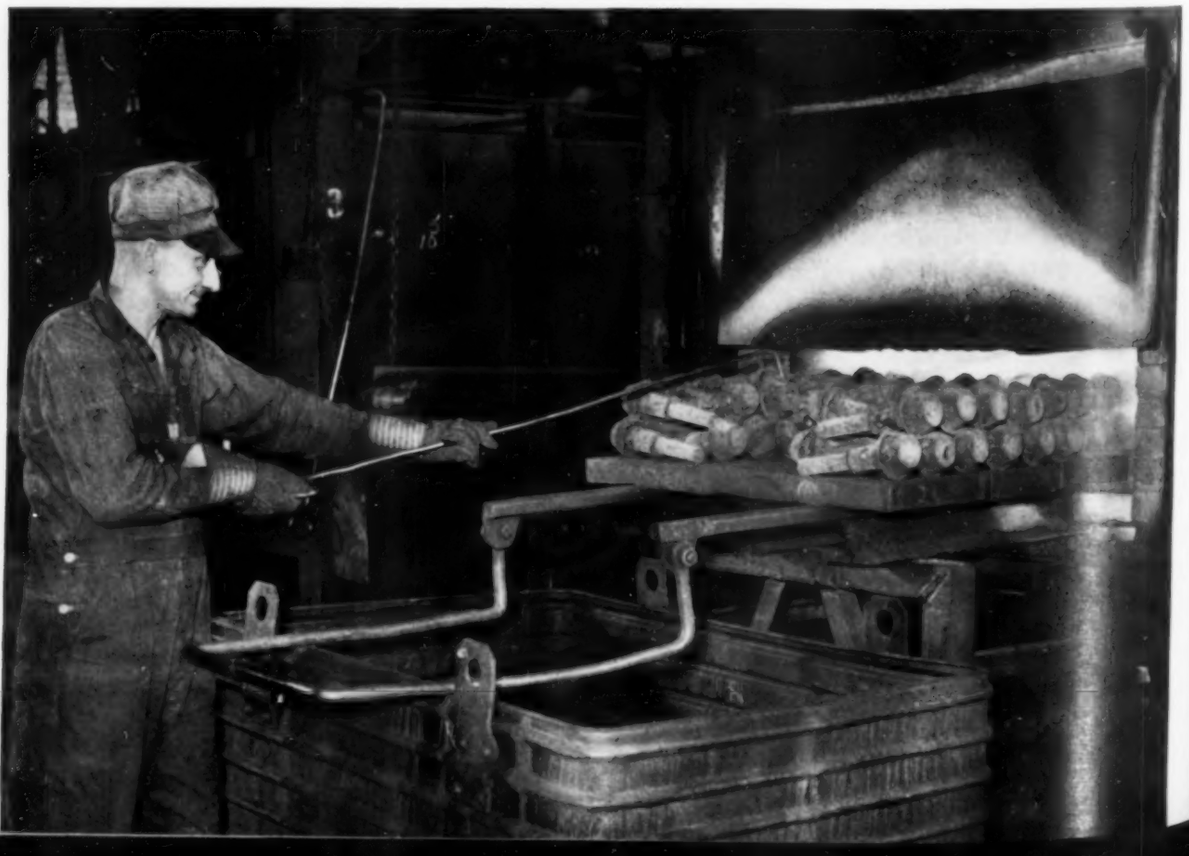
On the other hand, a temperature as low as 1450° F., where the stability of austenite is quite low in fine-grained steels particularly, produced an extremely soft material, yet the structure also had so much divorced cementite that broaching costs increased tremendously. Annealed structures with high percentages of spheroids and divorced cementite are also to be avoided because they are prone to be sluggish in going into solution during the hardening heat. With short heating cycles, such as are used in salt baths, this type of structure is apt to be more critical and cause considerable inconvenience and trouble.

Brinell hardness checks are made on a percentage of the gears as they come out of the annealing furnace in order to keep as close to the required cycle as possible. In addition to that, a traveling couple is run through each annealing furnace, embedded in a gear, once a week to check heating conditions against the microstructure of the heat treated gear.

Distortion from hardening is one of the evils so hard to control, yet so vitally important as far as good, quiet transmissions are concerned. Five checks are made in advance of production of a heat, in order to determine the allowance to be compensated for in cutting angles. Unwinding of helical gear teeth and run-out of gears, such as the counter and clutch gears, are the usual occurrences. This is more noticeable when salt baths are used for heating prior to quenching.

Cyanide salt baths are used as the heating medium for a part of our gear production. We find that a quench over the Ar point gives a minimum amount of distortion and greater consistency of movement (change of dimension). Heat treatment is done in a "jack rabbit" equipment having four cyanide pots in line with temperature settings as follows: No. 1 pot, 1325° F.; No. 2 pot, 1500° F.; No. 3 pot, 1500° F.; No. 4 pot, 1325° F. Oil quench and wash tanks follow in the line. Thermostatic temperature control on the oil quench holds it at 100 to 110° F. Oil turbulence is avoided as much as possible by the use of a time switch which shuts off the oil pumps the moment the gears hit the quench. Using a six-minute cycle, a load of 60 lb. per rack is carried from pot to pot, quenched and washed, then drawn in a vertical furnace, set at 450° F., for a period of two hours. Gears after hardening and drawing are Rockwell tested 100%, holding to a minimum Rockwell hardness of C-50. Bearing and run-out checks are made

Tray-Loads of Differential Gear Forgings Coming From an Annealing Furnace



at various intervals for distortion. In addition to that, toughness is tested periodically from each of our heat treating lines by breaking the teeth out of a few gears using a chisel and a 3-lb. hammer. R. B. Schenck has described these operations in S.A.E. *Journal*, June 1936.

Decarburization in a Gas Carburizer

Only a portion of the transmission gears is now treated in cyanide salt baths. We are gradually working into atmosphere control, and at the present time have two such furnaces for gears in our plant, both of which are giving more satisfactory gears by far for consistency in distortion, toughness, hardness, and cleanliness. A case 0.005 in. thick is desired, and this is checked for depth and type (microscopically) twice every 24 hr. With the type of atmosphere used in the furnace, there is no heavy hypereutectoid case, but one approaching 0.70% carbon. There is also a slight amount of decarburization which is variable from top to bottom of a gear tooth, and which, if desired, can be eliminated by introducing small percentages of propane gas in the muffle. Decarburization is somewhat dependent on the amount of CO_2 and O_2 in the gas, and it usually varies from slight to 0.0001 in. at the top of the gear tooth to as deep as 0.0003 in. at the bottom of the tooth. This has not been detrimental and has not caused any pitting under severe tests, nor undue fatigue failures. A case can be increased to 0.010 in. or more in these furnaces with no trouble, so that if a gear steel is desired with lower carbon (0.30 to 0.35%) — and there is a tendency in that direction at the present time — it could be handled very conveniently with slight adjustments in gas, time and temperature.

Although low carbon surface on high carbon stock is known to be quite detrimental to the endurance of spring steel, slight amounts of decarburization at the base of a gear tooth, if backed by a good eutectoid layer, may be beneficial. This, to my knowledge, has never been proven, but there may be some logic to it for this reason: When a load is applied there is bound to be some deflection in the gear tooth, and with a thin layer of decarburization at the base of the tooth, which means ductility on the surface at least, there should be less likelihood of rupture *at the surface* of the metal than there would be if there were full hardness and case (which means greater brittleness and stiffness) up to the outermost layer.

Heat Treating for Machinability

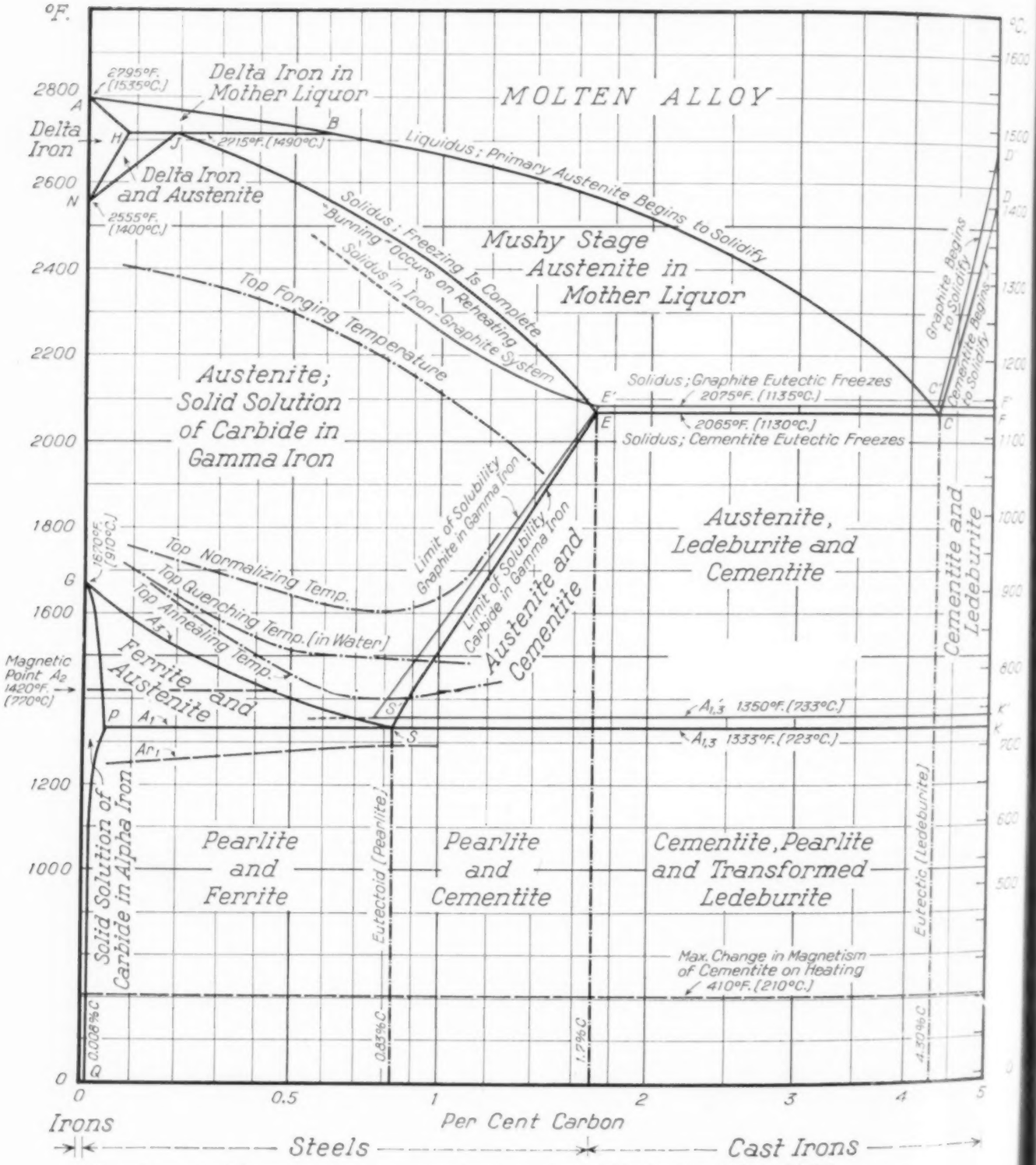
Differential gears, of which the ring and pinion are the most important, will, for sharpness of control, come in the same category as transmission gears. Nickel-molybdenum steel, specification 4620-A, grain size 6 to 8, is used because of its exceptionally good physical properties after a 1700° F. direct oil quench. Toughness and impact value were quite important in the old conventional design of spiral teeth on bevel gears. However, with the advent of hypoid gears, where load application is different and sliding frictional wear comes into the picture in a greater degree, they are probably of secondary importance; *now* it is a problem of greater wear and scoring resistance, wherein harder surfaces rather than toughness are essential.

One of the things that has caused considerable worry and annoyance is the machinability of 4620-A. The finish on the ring and pinion gears is such that any grooving or scratches in cutting, that cannot be eliminated in the lapping operation, are conducive to noisy differentials. Whether the roughness encountered in cutting these gears is due to fine grain in the steel, or to the incorrect annealing or normalizing cycle, is hard to say. At any rate, a normalizing cycle at 1750° F. (air cooled) is used on ring gears, which gives a Brinell hardness of 156 to 174. Since it seems necessary to keep pinion gears softer, due to the different method of cutting, they are heated to 1750° F. and cooled slowly, and so held to a Brinell hardness of 149 to 163. In spite of all the consistency that can be maintained in the chemistry of the heat, forging, normalizing, or annealing, a heat will often show very poor machining results. This has frequently been traced back to dirt, silicate inclusions, or spalled refractories, but an equal number of times there has been no apparent reason for such erratic machining. There is probably something in the melting practice or the heat itself conducive toward poor machining, and the thought naturally occurs that perhaps it may be a characteristic property of nickel-molybdenum steels to be a little more difficult to control; they are sometimes prone to hold products of deoxidation within the melt which may or may not be microsopic in size and are entirely overlooked.

Carburizing and hardening of ring and pinion gears offer no particular obstacles. All heats coming to the Buick plant are code

EQUILIBRIUM DIAGRAM FOR STEEL (IRON AND IRON CARBIDE)

Approximate Iron-Graphite Diagram in Blue



Except as noted hereafter, lines are reproduced by courtesy of The Engineering Foundation from diagrams published in one of the Alloys of Iron Monographs: "Alloys of Iron and Carbon," Vol. I on Constitution, by Samuel Epstein.

Forging and heat treating temperatures from Recommended Practices, 1936 ASM Metals Handbook.

Solidus in Iron-Graphite System according to Kaya, Honda and Endo, *Science Reports*, Tohoku Imperial University, 1925 and 1927.

Ar_1 according to Hoyt and Dowdell, "Metals and Common Alloys," for cooling rates of 1° C. in 3 sec.

Line GPQ according to J. H. Whiteley, *Journal*, Iron and Steel Institute, 1936.

Magnetic lines according to Kotaro Honda, 60th Report, Imperial Japanese Research Institute.

Solidus in graphite system left of E' as suggested by Harry A. Schwartz.

lettered and carried as such throughout all operations to the finished assembly for identification. Gears are packed in cylindrical boxes with a 3 to 1 mixture of carburizing compound, heated to 1700° F. in a pusher type furnace on a ten-hour cycle for a case depth of 0.040 to 0.050 in. and quenched direct from the pot. Test plugs of the same chemistry are put in every box to check depth of case. The file test is the most reliable check for hardness at the surface, since other tests are rather inconvenient to make because of the shape of the gear and furthermore, do not add much information to that given by the file.

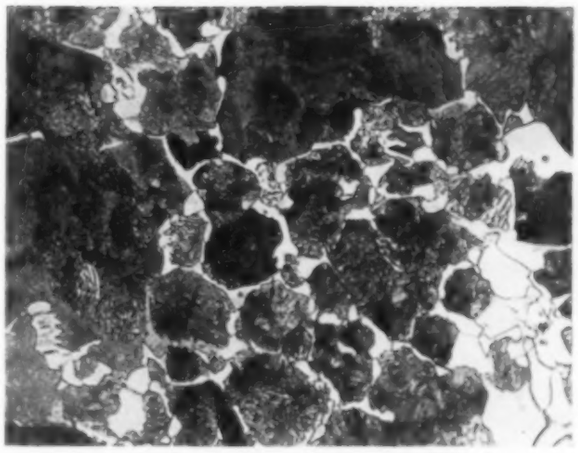
The remaining gears in the differential, which are the side pinion and intermediate gears, are purchased with grain size No. 5 to 7; side pinions are S.A.E. X1015, cold drawn; intermediate gears are forgings from S.A.E. 1115, hot rolled. These gears are also carburized to the same depth of case as the ring and pinion gears and quenched direct in water.

Treatment of Medium Manganese Steels

Manganese steel of the S.A.E. T1300 series, hot rolled, has become one of the popular steels used in car construction for important parts such as knuckles, steering arms, supports, and rear axle shafts. It responds very successfully to forging, heat treating and machining; uniform physical properties with draw temperatures of 800° F. and up can be anticipated. On all heats received, a 1-in. round tensile bar is forged, heat treated, machined and ground to the standard 0.505 in. diameter, pulled and held to the following minimum figures: Ultimate strength, 140,000 psi.; yield point, 125,000 psi.; 15% elongation in 2 in.; 50% reduction of area; "P" value of 88.

Particular emphasis is laid to this "P" value, which is figured from ultimate strength expressed in thousands, and ductility as shown by per cent reduction of area. The formula is $P=(S+6R)\div 5$ and using the above mentioned figures 88 will be the result.

This steel is also purchased with fine grain (No. 6 to 8) with our dirt rating of No. 1 minimum. It is quite important to get as clean a steel as possible for a dirt stringer at the surface of a knuckle or steering arm, for instance, is very apt to cause early fatigue failure. Practically all of the T1300 specification forgings are oil quenched with the exception of rear axle main shafts, which are partially hardened in water.



Manganese Steel, 1340-A, as Received in Annealed and Turned Bar Stock for Transmission Main Shaft. Nital etch; magnified 500 diameters

Drawing temperatures range from 800 to 1200° F. A 1200° F. draw is as high as should be used on these steels, for with the apparent rapid rate of spheroidizing at temperatures higher than 1200° F. uniform physical properties cannot be maintained. It has been found unnecessary to normalize manganese steel forgings after forging and before heat treating, because they refine quite readily in one heat, eliminating the forging structure.

Treatment of Carbon Steels

By far the greatest item of tonnage which goes toward the manufacture of a car is the crankshaft. A rather rigid specification for this material is upheld mainly to promote better machinability. Special S.A.E. 1045 steel is used with coarse grain (No. 2 to 4) and sulphur addition to 0.055% which we believe does promote better machining with no detriment to the physical properties. In addition, a section of a crank from each heat is cut parallel to the axis, ground and acid etched; there are indications that a crank that etches very readily is the most durable from the machining standpoint, and therefore is requested. All crank heats are code lettered and carried as such through all machining operations to the final assembly in order to check the machining performance of each individual heat.

In order to maintain any consistency of machining performance on crankshafts, it is quite essential that the heat treatment be uniform. Any shortening of time in the high heat, quench or draw will reflect back on the machin-

ing operations. A temperature of 1650° F. with 1½ to 2 hr. in the high heat, depending on the size of the crank, at least 2 min. in the quench and 3 hr. in the draw is considered a fairly safe cycle. Using a draw temperature of 1100° F., a Brinell hardness in the range between 229 and 269 is maintained.

One of the new steels which has entered into automobile construction for parts requiring medium tensile strength is a special S.A.E. 1050, with fine grain (No. 5 to 7) with a manganese content of 0.70 to 1.00%. This steel may be classed in a grade between carbon and alloy steel, perhaps a "semi-alloy steel." With an oil quench from 1550° F. on such parts as front wheel control arms and intermediate steering arms, it will show fairly good hardenability and give sufficiently high physical properties, providing there is no great degree of abnormality in the microstructure. Such a steel undoubtedly has a field for other forgings as well, such as crankshafts, camshafts and transmission mainshafts. This is really a place where grain size control has worked out quite successfully and brought to life steels which have formerly been out of the picture in car construction.

Heat Treatment Tests on Spring Steels

Spring steels, both rounds and flats for front and rear, are made of silico-manganese steel, S.A.E. 9260. The flats do not offer very serious difficulties except for surface defects and decarburization; the chemistry and inclusion rating are quite consistent. On the helical coil springs for the front end, however, much more precaution is taken for surface defects and decarburization because it is the outermost fiber that is most highly stressed, and any defects at the surface will, as a rule, cause localized stresses and early fatigue failure. Manufacturing operations were shown interestingly in a pictorial story in METAL PROGRESS in February.

Material for coil springs is purchased hot rolled, ground close to size. Decarburization and surface defects are checked by an acid etch test, and decarburization and hardenability by a sample heat treatment. This heat treat test, by the way, is carried out on every new heat and every different size of round bar in every heat. By prearrangement, the mill furnishes six prolongs (which are bars 12 in. over the regular length) on every new size from the heat. The prolongs are cut off and a hole drilled in one end through which a wire is strung for handling. A small electric muffle furnace set at a temperature of 1600° F. is used for heating. The total time cycle is 20 min., after which the pieces are quenched in oil individually with uniform vertical agitation, and then shot blasted. The shot blast is the type used for cleaning hardened high speed steel tools, and it very readily shows up the hard and soft areas on the pieces treated. Soft and hard spots, as revealed, are then Rockwelled and held to a C-55 minimum. Spots showing low readings are cut for micro-examination to note amount of decarburization and general structural conditions.

The above test offers a very good control

Final Inspection of Spline Gear

for coil spring material, and the shot blast, with variations in size of shot and velocity of application, may have possibilities in testing the hardenability of steels; variations in surface hardness can quite easily be detected — something difficult to do otherwise.

Transmission mainshaft material is made of specification 1340-A, hot rolled, fine grain (No. 6 to 8), turned close to size, and annealed by the source to a Brinell hardness of 197 to 217, with pearlitic structure as free from divorced cementite and spheroidized sorbite as possible. This, as mentioned before, gives the most desirable structure for turning and hobbing shafts. Since the material is also purchased free from decarburization, the mills are somewhat prone to furnish a spheroidal structure, because a low temperature in the neighborhood of 1300° F. is all that would be required and would cut down decarburization at the surface.

Another thing we ask for on this material, and seldom get, is freedom from banding. With banded structures, there is more likelihood of distortion and, frankly, this shaft in the hardened state is not so easy to straighten! Good heat treating practice must be maintained to hold breakage down to a minimum.

Every shipment from a heat, which usually represents one annealing charge at the mill, is checked for structure and hardness, and even though the source is constantly making a serious effort for uniformity in annealing, there is still quite a big variation from charge to charge and from one part of a charge to another, due perhaps to the excessive loads that are handled. It would seem possible to construct a continuous pusher type of furnace for annealing bars, so that lighter loads could be handled and a more uniform product obtained.

Treatment of Cold Drawn Rods and Tubing

Cold drawn manganese steels are handled in much the same way as transmission mainshaft steel with equally as great care in control of its chemistry, physical properties and machining performance.

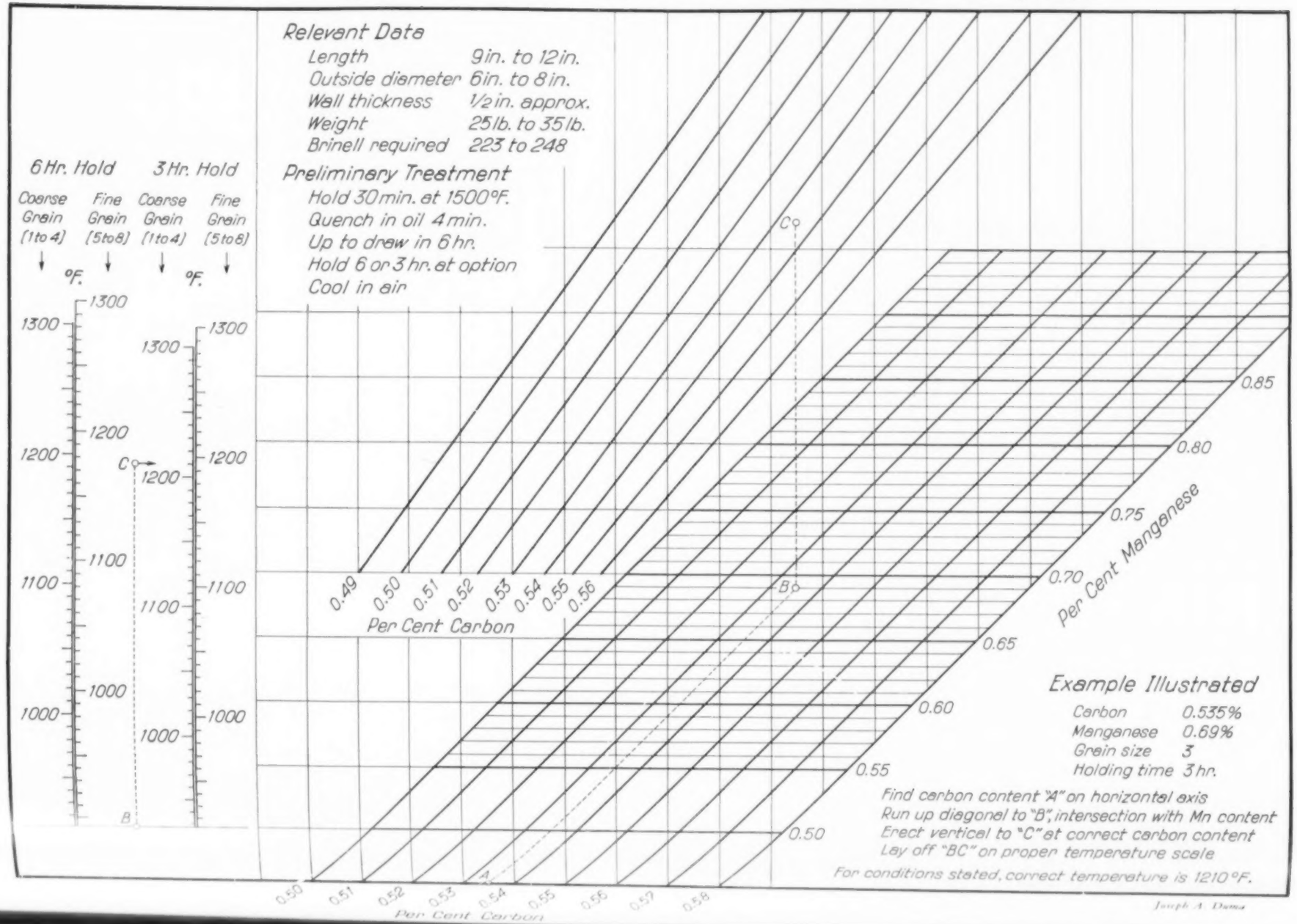
Cold drawn carburizing steels, S.A.E. X1015 and 1115, used for such parts as piston pins, knuckle pins, support pins, and shafts are purchased with fine grain (No. 5 to 7). The greatest variation in such material is in normality and hardenability. In changing from coarser to a finer grain, there is a noticeable increase in hardening difficulties so that more drastic quenches are resorted to in order to keep the percentage of spotty hardening low.

Cold drawn tubing, S.A.E. 1010, used particularly for valve rocker arm shafts (which are carburized, cooled in the box, then rehardened, and quenched in water between rolls) is usually very spotty in hardness and warped when the material shows indications of abnormality on the McQuaid-Ehn test. In order to hold the degree of abnormality low, the mills usually work to a higher manganese content — approximately 0.60% maximum. In cases where we have processed valve rocker arm shafts from abnormal steel, we found, strange as it may seem, that the higher the hardening temperature the more spotty the shafts became (which is the reverse of published information about abnormal steels), and that the best results were obtained using a low temperature of about 1400° F. and a quench in brine or water.

The greatest bulk of cold drawn material is S.A.E. 1112 and X1112 bessemer screw stock, the latter with sulphur specified as high as 0.30%. Such high sulphur is selected because of its free machining properties at high speeds, and this amount is sufficient with our present set-up of cutting speeds and automatic machines. Furthermore, a number of our parts made from X1112 steel are carburized and hardened, and a higher sulphur would not be the most desirable. However, the time will undoubtedly arrive when faster working machines will be desired and higher sulphur content will be specified.

Metallurgical inspection of the finished parts is watched carefully. For the important parts in the car a 100% Brinell, Rockwell or file test, as the case may be, is maintained. In carburizing, test plugs are placed in every box to check depth of case; bend tests are made whenever feasible for core toughness. Temperature recorders are standardized periodically, and whenever possible traveling couples are used to verify furnace conditions. Oftentimes, when everything seems to be running smoothly, there is a feeling that the inspection is a little too expensive, but just about that time a few failures will come in for investigation. Immediately there is a tightening up of the inspection instead of the reverse! The time has not arrived when anything can be overlooked metallurgically. There is too much at stake such as public safety, car reputation, competition and a happy, satisfied customer.

Draw Temperatures for S.A.E. 1050 Basic Steel Forgings



Production Carburizing Revolutionized in 30 Years

By Ernest F. Davis
Chief Metallurgist
Warner Gear Co.
Muncie, Ind.

Quenching a Tray-Load of Small Work From a Pit Type of Carburizing Furnace

"CARBONIZING," as it was called until about 15 years ago, is probably one of the oldest of the ferrous processes. Metallographic examination of tools from Egyptian tombs shows that they were made by welding pieces of iron together and then carburizing the edge to about 0.80% carbon. Steel articles for many centuries were made in small workshops with rudely constructed furnaces by processes unbelievably slow and tedious. Unquestionably much useful steel was made during the Middle Ages by carburizing with animal or vegetable carbon or nitrogenous bodies. The manufacture of Sheffield steel is also well enough known to indicate the important place which the cementation process held as late as a half-century ago.

In contradistinction to cementation, box carburizing almost reached the point of obsolescence toward the end of the last century, except for the manufacturers of gun mechanisms and sewing machines who employed it for small parts. With the advent of bicycle ball bearings, the bearings and cones were carburized with ingredients exactly the same as those described by writers from the 14th to the 18th Century. Furthermore the process was almost as crudely done 40 years ago as several centuries before. In one plant quite an advance in furnace design was accomplished in 1906 when eight coal-fired furnaces were grouped into one unit and the flues connected to a tall central stack! Temperatures prior to the earliest pyrometers in 1905 were more or less mythical, for the fireman attempted to keep the temperature at a "dark orange." The cost to carburize during this period was from 10¢ to 20¢ per lb. and the quality of work usually poor.

With the advent of "fuel oil," burners were devised to spray it into a combustion chamber and the familiar under-fired, rectangular, box carburizing furnace came into being. It is still in service in many American plants. One of the largest installations in the United States so operated between 1914 and 1923. Pyrometer

Abstract of a paper for the Carburizing Symposium, 1937 ✪ Convention

Conversion, Fahrenheit to Centigrade

Based on tables published by National Bureau of Standards

All decimals are repeating decimals. For example, the Centigrade equivalent of 300 degrees F. is indicated in the table as 148.8. The last figure "8" being a repeating decimal, the accurate value is 148.888...

Degrees Fahrenheit	0	10	20	30	40	50	60	70	80	90
	Degrees Centigrade									
— 400	— 240.0	— 245.5	— 251.1	— 256.6	— 262.2	— 267.7	.....	.....	.....	.....
— 300	— 184.4	— 190.0	— 195.5	— 201.1	— 206.6	— 212.2	— 217.7	— 223.3	— 228.8	— 234.4
— 200	— 128.8	— 134.4	— 140.0	— 145.5	— 151.1	— 156.6	— 162.2	— 167.7	— 173.3	— 178.8
— 100	— 73.3	— 78.8	— 84.4	— 90.0	— 95.5	— 101.1	— 106.6	— 112.2	— 117.7	— 123.3
— 0	— 17.7	— 23.3	— 28.8	— 34.4	— 40.0	— 45.5	— 51.1	— 56.6	— 62.2	— 67.7
0	— 17.7	— 12.2	— 6.6	— 1.1	+ 4.4	+ 10.0	+ 15.5	+ 21.1	+ 26.6	+ 32.2
100	37.7	43.3	48.8	54.4	60.0	65.5	71.1	76.6	82.2	87.7
200	93.3	98.8	104.4	110.0	115.5	121.1	126.6	132.2	137.7	143.3
300	148.8	154.4	160.0	165.5	171.1	176.6	182.2	187.7	193.3	198.8
400	204.4	210.0	215.5	221.1	226.6	232.2	237.7	243.3	248.8	254.4
500	260.0	265.5	271.1	276.6	282.2	287.7	293.3	298.8	304.4	310.0
600	315.5	321.1	326.6	332.2	337.7	343.3	348.8	354.4	360.0	365.5
700	371.1	376.6	382.2	387.7	393.3	398.8	404.4	410.0	415.5	421.1
800	426.6	432.2	437.7	443.3	448.8	454.4	460.0	465.5	471.1	476.6
900	482.2	487.7	493.3	498.8	504.4	510.0	515.5	521.1	526.6	532.2
1000	537.7	543.3	548.8	554.4	560.0	565.5	571.1	576.6	582.2	587.7
1100	593.3	598.8	604.4	610.0	615.5	621.1	626.6	632.2	637.7	643.3
1200	648.8	654.4	660.0	665.5	671.1	676.6	682.2	687.7	693.3	698.8
1300	704.4	710.0	715.5	721.1	726.6	732.2	737.7	743.3	748.8	754.4
1400	760.0	765.5	771.1	776.6	782.2	787.7	793.3	798.8	804.4	810.0
1500	815.5	821.1	826.6	832.2	837.7	843.3	848.8	854.4	860.0	865.5
1600	871.1	876.6	882.2	887.7	893.3	898.8	904.4	910.0	915.5	921.1
1700	926.6	932.2	937.7	943.3	948.8	954.4	960.0	965.5	971.1	976.6
1800	982.2	987.7	993.3	998.8	1004.4	1010.0	1015.5	1021.1	1026.6	1032.2
1900	1037.7	1043.3	1048.8	1054.4	1060.0	1065.5	1071.1	1076.6	1082.2	1087.7
2000	1093.3	1098.8	1104.4	1110.0	1115.5	1121.1	1126.6	1132.2	1137.7	1143.3
2100	1148.8	1154.4	1160.0	1165.5	1171.1	1176.6	1182.2	1187.7	1193.3	1198.8
2200	1204.4	1210.0	1215.5	1221.1	1226.6	1232.2	1237.7	1243.3	1248.8	1254.4
2300	1260.0	1265.5	1271.1	1276.6	1282.2	1287.7	1293.3	1298.8	1304.4	1310.0
2400	1315.5	1321.1	1326.6	1332.2	1337.7	1343.3	1348.8	1354.4	1360.0	1365.5
2500	1371.1	1376.6	1382.2	1387.7	1393.3	1398.8	1404.4	1410.0	1415.5	1421.1
2600	1426.6	1432.2	1437.7	1443.3	1448.8	1454.4	1460.0	1465.5	1471.1	1476.6
2700	1482.2	1487.7	1493.3	1498.8	1504.4	1510.0	1515.5	1521.1	1526.6	1532.2
2800	1537.7	1543.3	1548.8	1554.4	1560.0	1565.5	1571.1	1576.6	1582.2	1587.7
2900	1593.3	1598.8	1604.4	1610.0	1615.5	1621.1	1626.6	1632.2	1637.7	1643.3
3000	1648.8	1654.4	1660.0	1665.5	1671.1	1676.6	1682.2	1687.7	1693.3	1698.8
3100	1704.4	1710.0	1715.5	1721.1	1726.6	1732.2	1737.7	1743.3	1748.8	1754.4
3200	1760.0	1765.5	1771.1	1776.6	1782.2	1787.7	1793.3	1798.8	1804.4	1810.0
3300	1815.5	1821.1	1826.6	1832.2	1837.7	1843.3	1848.8	1854.4	1860.0	1865.5
3400	1871.1	1876.6	1882.2	1887.7	1893.3	1898.8	1904.4	1910.0	1915.5	1921.1
3500	1926.6	1932.2	1937.7	1943.3	1948.8	1954.4	1960.0	1965.5	1971.1	1976.6
3600	1982.2	1987.7	1993.3	1998.8	2004.4	2010.0	2015.5	2021.1	2026.6	2032.2

Examples

— 246.0° F. = — 151.11° C. — 3.33° C. = — 154.44° C.
2423.5° F. = 1326.66° C. + 1.66° C. + 0.27° C. = 1328.61° C.

Values for Interpolation

Deg. Fahrenheit	1	2	3	4	5	6	7	8	9
Deg. Centigrade	0.5	1.1	1.6	2.2	2.7	3.3	3.8	4.4	5.0

leads were connected to a master control station, furnace temperatures were checked periodically, and the supply of fuel increased or lessened at each furnace accordingly. Packing and handling of boxes into and out of the furnace was purely muscular and rather expensive.

From 1910 to 1920 much carburizing was done on motor car parts — nearly all gears, stress-carrying and wearing parts, even including crankshafts. This was a transition period in more ways than one, for during this decade we find the metallurgist gradually replacing the blacksmith foreman as the man in charge of heat treating operations. The thermocouple also replaced the human eye.

Changes in the nature of solid carburizers are interesting. Raw, ground bone appears to be the standard material at the turn of the century. This was heavy, costly, and could be used but once, and therefore contributed much to the high cost of casehardening in the early days. It was superseded by compounds composed largely of charred leather with bone, and bone with charcoal. A very popular one called "hydrocarbonated boneblack" was composed of heavy oil and finely ground bone. Leather and charcoal composed another mixture.

After 1910 the gradual trend was toward the energized or chemical types. These were mixtures of charcoal, coke, or retort carbon with various carbonates, and weighed from 22 to 32 lb. per. cu.ft. This was a big step toward the reduction of casehardening costs. Instead of a 50-50 mixture, which was common practice when bone was used, a mixture of 80% old and 20% new became the mixing formula. In present-day practice compound is re-used indefinitely, being merely regenerated by replacing the volume lost by burning and dusting.

Carburizing boxes 30 years ago were of cast iron, cast steel, annealed and unannealed malleable iron, and occasionally pressed steel or pipe. Cast iron was cheapest and most commonly used, giving about 250 hr. life before failure. Good cast steel averaged about 450 hours at heat and white iron and malleable 350 to 400.

Boxes were packed with steel parts buried in compound, a lid was placed on top, and the edges luted with mud or fireclay. The furnace, previously brought to temperature, was loaded with as many boxes as it would hold, which, of course, upset the heat balance. Boxes in more favored localities in the furnace chamber would heat up faster than the others, even with the closest regulation of burners, which was sometimes missing. Actual tests showed large differences in the heating cycle in the various boxes, with corresponding differences in the product. A case depth variation of 0.010 in. was regarded as the closest limit possible.

Cost in these plants from 1910 to 1921 was considerably lower, however, and varied from 3¢ to 10¢ per lb.; often it was nearer the 10¢ limit. Since that time many steps have been taken toward lowering the cost, but primarily toward improving the uniformity of the result.

One of the first steps toward improving uniformity was automatic fuel control. This was preceded by automatic signaling pyrometers utilizing colored light. Even though oil and gas proportioning valves were employed in other types of furnaces for many years, they were seldom used in carburizing furnaces until about 1920, and then only because of competi-

Work Around the Old-Fashioned Rectangular, Box Carburizing Furnace Was Hot and Dirty

tion by electric box furnaces wherein heat control was simplified.

A second step toward improved uniformity was the advent of alloy boxes. In 1918 Henderson patented the high nickel-chromium alloys for carburizing boxes and the life was increased to 8,000 to 10,000 hr. It was quickly demonstrated that such alloys, even at $1.25 per lb., were more economical than a cast steel box at a few cents. Particularly the decreased frequency of cracked boxes improved the quality of carburized work. Another important contribution of the high alloy toward heat treating progress (though later adopted) was the possibility of placing roller rails and other metallic parts within the hot furnace itself.

However, the first important step toward eliminating the uncertainties of box furnace practice was the rotary hearth furnace — turret-shaped electric furnaces 18 to 30 ft. in diameter with annular hearths 5 to 15 ft. wide. Charging and discharging doors were separated by an intervening wall and the operation of the furnace was such that each box passed through the same heating cycle automatically and the furnace was at no time chilled by a load of cold boxes. Most of the publicity given these furnaces was relative to their economy, but little was said regarding their more important possibilities of producing better carburized work.

Many tunnel type furnaces were built from 1923 to 1929 for gas, electric or oil firing. Carburizing boxes were laid on trays and pushed by exterior mechanisms the entire length of the furnace and thus passed through controlled heating zones. Although many metallurgists preferred electric heating, for radiant heat is very effective when large masses are to be heated, the high cost per electric unit forced the design of the well-known counterflow furnaces. These required very long furnaces and long carburizing cycles (25 to 35 hr.) but were quite efficient in the utilization of heat, since the boxes were discharged at about 800° F.

By this time the cost of carburizing had dropped to approximately 1¢ a lb., but varied from 0.8¢ to 1½¢ depending on the case depth and type of work.

With the introduction of the fine-grained shallow-hardening steels, it was discovered that such steels could endure prolonged carburizing treatment without coarsening the austenitic grain size and such parts could be quenched directly from the box without further treatment except a tempering operation. Adoption of this type of steel has caused many plants equipped with counterflow furnaces to rebuild them in a straight-through design so the boxes can come out hot to the quench. Aside from metallurgical advantages, it is doubtful if the over-all hardening costs are reduced very much; comparative costs in one plant where both counterflow and straight-through furnaces are used showed no saving over the box cool and reheat.

Trend Toward Gas Carburizing

The trend today seems to be toward some form of carburizing in a controlled gas atmosphere. Gas carburizing is by no means new. In this country it was introduced in the Machlet furnace about 1910, which consisted of a slowly rotating horizontal retort revolving on rollers and externally heated by gas. Several such installations were in operation between 1914 and 1918 which utilized gas under pressure for carburizing small parts. The method was also quite effective when the retort carried some solid carburizer.

The modification which attained success was the electrically heated pit type of furnace. Work was placed in racks or in perforated baskets, lowered into the furnace, and a sealing cover bolted on. On the underside of the cover is a fan on a vertical shaft; a large drip lubricator introduces oil into the furnace where it is vaporized and circulated throughout the work. The decomposition of the hydrocarbons produces the carburizing gas and a case of 0.040 to 0.060 in. is made in 5 to 8 hr. depending upon the depth. While some unsatisfactory reports have been received, there are no doubt several advantages to these furnaces, particularly the short carburizing cycles.

In all these gas carburizers the hydrocarbon was introduced without previous treatment except partial dehydration or dilution with air. About 1930 was introduced a continuous gas carburizer wherein a hydrocarbon gas is mixed with carbon dioxide (flue gas) and flows through the retort with the work. Entrance and exit locks are required for the metallic muffle. There are apparently three distinct zones of action, one depositing finely divided carbon on the surface, the second where carbon is converted to carbon monoxide and absorbed by the steel, and third, where the high carbon at the surface of the steel diffuses inward. A case of 0.040 in. is possible in 4 hr., and 0.050 in. in 5 hr. total time. *(Cont. on page 366)*

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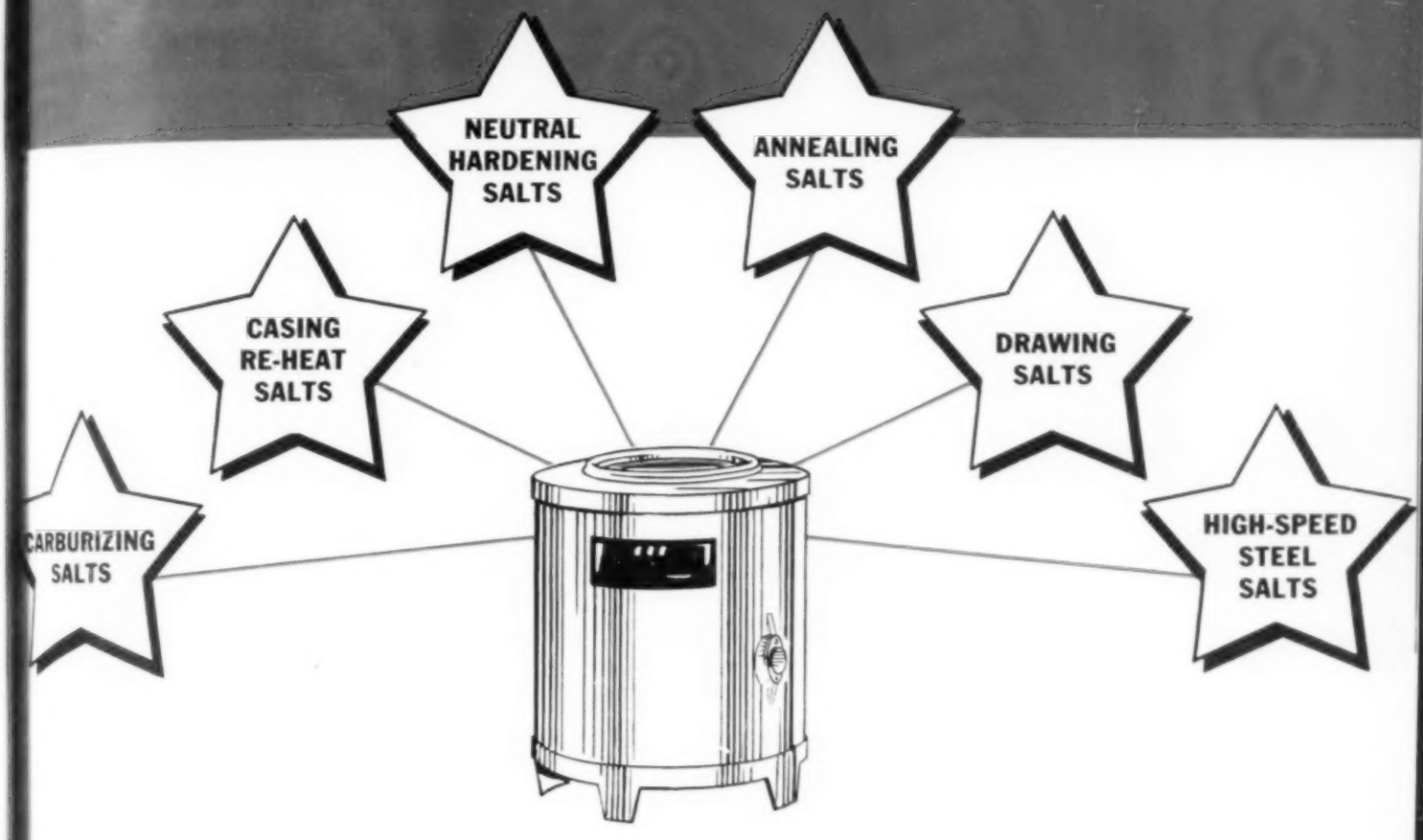

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OF PRODUCTS FOR THE METAL INDUSTRY

Carburizing

(Continued from page 350)

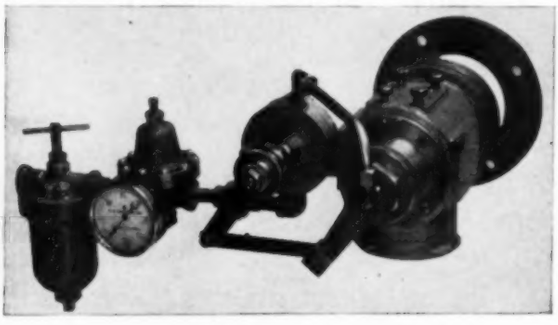
This has many obvious advantages over the heating of large quantites of inert material in the form of box and carburizing compound. However, the first cost and maintenance of the muffles is quite high. Costs range from ¾¢ to 1½¢ depending upon the depth of the case, but these figures could easily be increased if bad luck was experienced with the muffles.

Other continuous gas carburizers work on much the same general principles but with variations not only in mechanical design, but composition of carburizing gases and methods of introducing them.

Within the span of 35 years carburizing costs have been reduced from approximately 15¢ per lb. to less than 1¢ per lb. Instead of the work being done by crude, laborious methods, the furnaces and handling equipment have been almost universally mechanized. Where formerly this was one of the dirtiest of the heat treating operations, now modern furnaces are often placed directly in the production line. Instead of the uncertainty of the human eye in judging temperatures we have delicately balanced instruments controlling not only the temperatures within a few degrees but regulating the time cycle as well. Instead of bringing the heat to the box we have the work passing through carefully controlled thermal zones so that each box or individual piece has exactly the same increment of heating. Where formerly containers gave but a few weeks of life, we now have alloy parts yielding from one to eight years' continuous service. Uncertain case depth, irregular carburizing, and a host of defects which were the bane of carburizing practice for many years now no longer exist.

In the newest gas carburizing processes not only is the case depth held with exactitude, but the hyper-eutectoid zone can be made as deep as desired, or an eutectoid or hypo-eutectoid case produced at will. There is no question but that pack carburizing is steadily losing ground by the advent of the retort, pit type, and continuous gas furnaces.

The process of carburizing has progressed in one generation more than it did in all the previous century.



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Furnace Practices Improve Forgings

By Lloyd E. Raymond
Metallurgist
The Singer Mfg. Co.
Bridgeport, Conn.

Photo by Rittase

A STUDY of machine parts which had failed in service either from increasing speeds or from more severe requirements in the machines' operation disclosed that there was a great dissimilarity in the life of forged parts in identical machines operated under similar conditions. (The machines, by the way, are high speed sewing machines used in the textile trades and other manufacturing establishments which consume important quantities of woven fabrics.) It was found that forgings which were apparently of rugged design and well suited to outlast other parts not made from forgings were, nevertheless, failing in fatigue under repeated impact. Nearly every metallographic examination of the prematurely broken parts disclosed undesirable microstructural defects such as large grain size, fusion at the grain boundaries, and (in a few isolated cases) some traces of the structure called "ingotism," usually found in cast metal only, and consisting of the excess ferrite outlining fairly coarse grains and existing in some of the cleavage planes therein.

These failures were occurring in all types of steels among which were 0.12% carbon free-machining bessemer steel, low carbon and alloy openhearth carburizing steels, and eutectoid alloy and high carbon steels melted in the electric furnace. Nor were the failures limited to those parts receiving any particular types of heat treatment, as they occurred in parts used in the heat threated condition (including carburized and cyanide hardened), in normalized parts and in parts as forged. Without the metallographic examinations as verification, these facts alone were reasonable indication that the cause of the difficulties lay in the forging practices, and an immediate and thorough survey was ordered.

A check of the forging furnace was made and it was found that there was a wide variation in its temperature. The tendency was to operate at temperatures too high for best practice. It might be mentioned in fairness to the drop forger that when the furnace was very hot the bars were taken out before they reached the temperature of the forge.

Our first thought was to place an indicating pyrometer on the existing forge and require the operator to keep to the temperature speci-

fied. Another suggestion was that an automatic temperature control be installed. Both of these plans were rejected as inadequate. The slot in the forge was too short to hold and heat a sufficient number of bars to keep the operator busy when the furnace was operated at what was considered desirable temperatures. It was therefore decided to purchase a new furnace for forging which should have complete automatic and recording control.

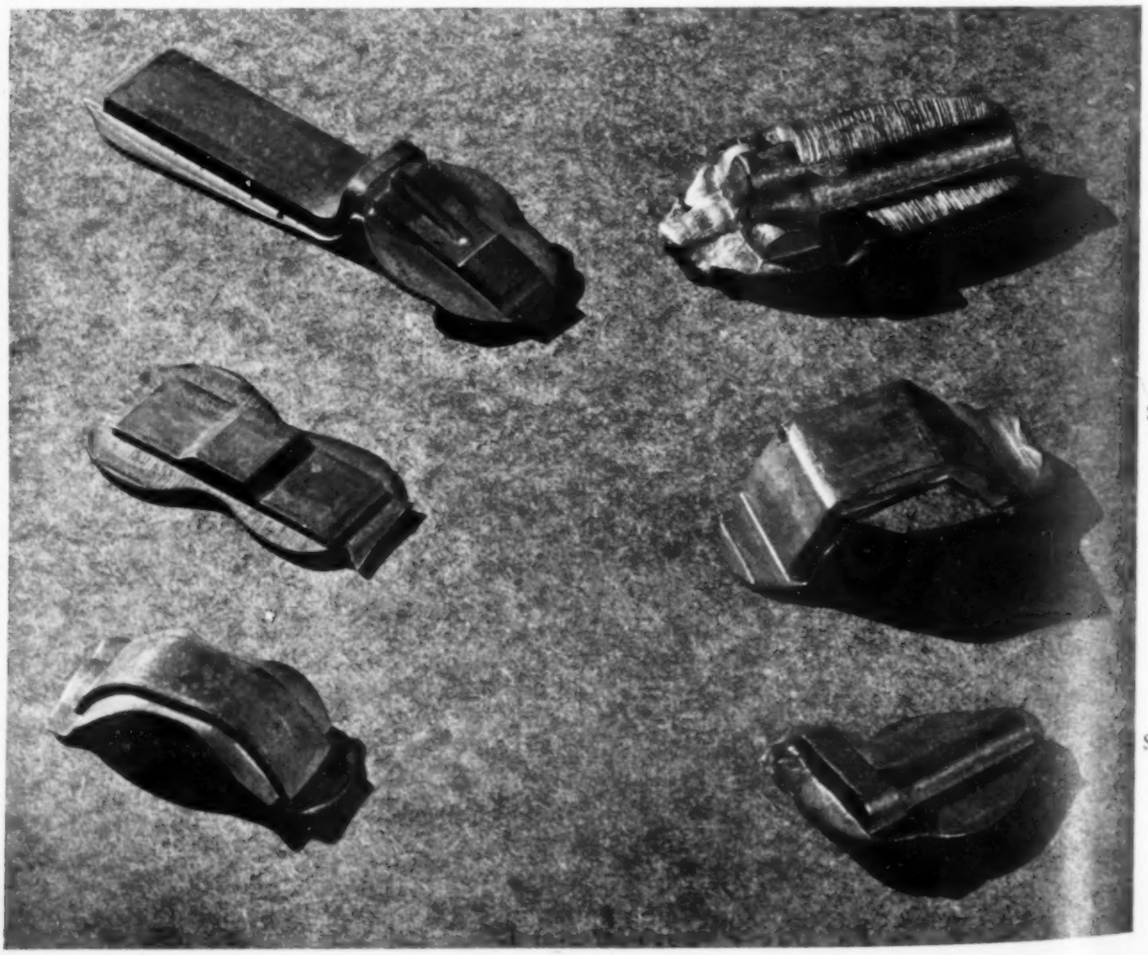
After a fairly comprehensive study of available fuels and furnaces, a slot type of bar heating furnace was ordered; it was fired with two burners designed to burn 28 to 32° Bé. fuel oil at 10-lb. pressure when supplied with air at 1½ to 2-lb. pressure. The inside dimensions of this furnace were 18 in. deep by 18 in. high by 27 in. wide, the slot being 27 in. long by 4½ in. high. For fuel economy this furnace was lined with 4½ in. of good grade firebrick backed up by 4½ in. of insulating brick made of diatomaceous earth. Oil was retained as the fuel; we believe that the free carbon in the oil flame reduced the volume of scale on the work and that which was produced was not very adherent and flaked off readily under the hammer. (Adherent scale, formed in atmospheres with much oxygen, reduces die life and damages the forgings.)

This furnace was controlled by an inexpensive air-oil valve of the on-and-off type. This very satisfactory mechanism was operated in turn by a recording and controlling potentiometer with a platinum thermocouple. The couple was protected by means of a double sillimanite tube with a secondary protection tube of fireclay refractory inserted through the back of the furnace at the same level as the bars being heated for forging. The furnace had an air screen before the slot to keep the operator as comfortable as possible.

The new forge was placed in operation about a year ago, and an immediate and marked improvement was noted in the quality of the drop forgings. Their grain size was controlled, as the finishing temperature of the hot working was kept as low as possible without working below the austenitic range of the steel. There was also a very noticeable improvement in the surface condition of the forgings, as the amount of adhering scale was greatly lessened.

However, as is usually the case with things that are new, other difficulties crept in. The furnace, being highly efficient as far as heat loss

Small Forgings From the Hammer, Prior to Heat Treatment or Any Cleaning Operation. Temperatures, as noted, are rather lower than customary practice, but close inspection will show where metal readily flows into small heat checks in the dies



through the walls was concerned, had to be equipped with burners with small orifices and low turn-down ratio to maintain the relatively low temperatures desired for forging some steels. There was therefore a sharp limit to the maximum heat that could be obtained; as a result the time required to heat this furnace from cold was 4½ hr., despite its efficient insulation and relatively small heat storage in the refractories. It should be said, however, that this disadvantage existed only after week-end shutdowns, as the furnace would be at 900° F. after a 14-hr. over-night shutdown. The 3-hr. loss of production on Monday mornings, although objectionable, could have been circumvented as several other costly conditions had been eliminated.

A further and more serious obstacle was present. This was the presence of foreign matter in the oil. This would be freely carried through the large burners on the old discarded forge, but was continually clogging up the small burner orifices in the new one, as well as fouling the strainers on the oil lines. Strainers and burners had to be cleaned at the most inopportune times.

At about this time the very interesting display of luminous flame gas burners by the North American Mfg. Co., at the Metal Exposition in Cleveland was noted. Although these burners were operating successfully on natural gas, none had been tried on manufactured city gas such as was being supplied to our forge plant. Natural gas has the reputation of burning much more slowly than manufactured gas. It was also brought out in our studies that the gas pressure in Bridgeport was but 2½ to 3 oz. per sq.in., which, although constant, was less than the minimum at which any of these burners had previously been operated.

After carefully studying the probable merits of this type of firing and balancing them against the estimated shortcomings, one of these burners was mounted on the side of the forge in place of an oil burner, the other oil burner being removed and the hole cemented up. The oil-air valve was replaced by a suitable gas-air valve of the same design, and the furnace was placed in operation as a gas-fired forge early in 1937.

Troubles experienced when the furnace was oil fired were over, and the surface condition of the forgings became further improved! The operator can now light the furnace with a match without danger of a flareback or puff and start heating bars for forging within 20 min., even when the furnace is cold after a several-day shutdown. Smoke, although not entirely eliminated, is barely perceptible, and the flame is longer than the oil flame.

The basic principle of these "luminous flame" burners is much the same as the diffusion type of combustion previously described in METAL PROGRESS. Gas and air are introduced in concentric streams without turbulent mixing and combustion occurs gradually as the air diffuses into the gas and the gas into the air. The result is also the transitory production of much incandescent carbon particles, which is responsible for the luminosity and rapid heating by radiation therefrom. In the particular type of burner we are using, a pilot flame of constant volume is produced at the center of the burner; the small amount of turbulence in our relatively short furnace has no ill effect on the combustion characteristics.

Scale now produced on our hot bars is even less adherent than that obtained by oil firing. It flies off the bar as soon as the hammer strikes it, leaving a clean, hot surface which has the least possible undesirable effect upon the dies. Control of temperature is ±15° F.; it can be narrowed if desired, but as this control is better than required for exceptionally good forgings, no attempt to make it finer has been made. We therefore have a wide range of temperature settings without changing any adjustments of the valves.

Steels now being forged include the following: S.A.E. 1015, 1112, 3120, 3135 and 4615, a 1.00% carbon toolsteel containing 0.30% manganese and less than 0.02% phosphorus or sulphur, and a high carbon nickel-chromium-molybdenum steel of the following analysis: 0.70% C, 0.60% Mn, 0.03% max. P, 0.03% max. S, 1.25% Ni, 0.75% Cr, and 0.25% Mo. Temperatures at start of forging are as listed in the table and it will be noted that they are from 150 to 200° lower than the maximum recommended

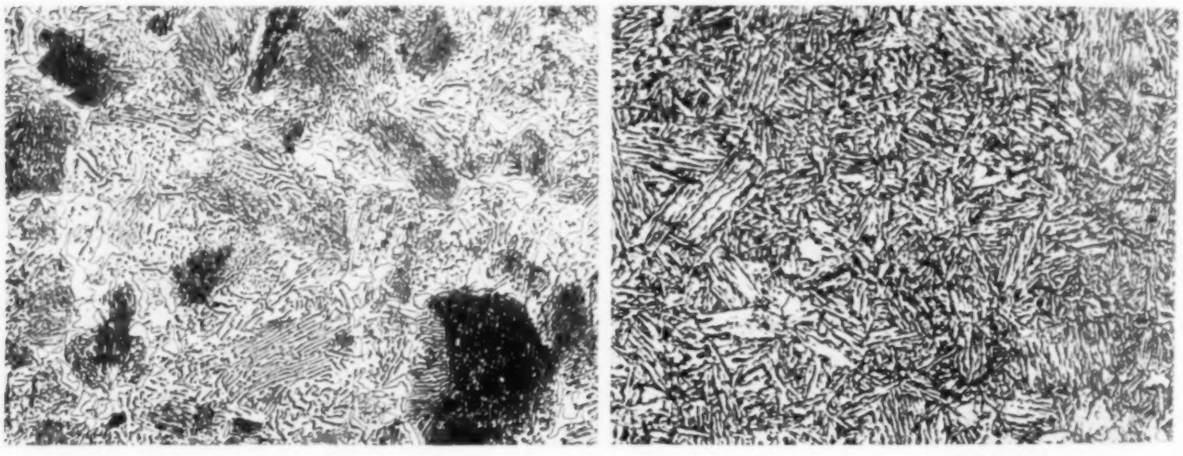
STEEL	FORGING TEMPERATURE
S.A.E. 1015	2200° F.
S.A.E. 1112	2200° F.
S.A.E. 3120	1950° F.
S.A.E. 3135	1950° F.
S.A.E. 4615	1950° F.
1% C Tool	1900° F.
Ni-Cr-Mo	1850° F.

in the Metals Handbook. If the Ni-Cr-Mo steel is heated above 1875° F., it becomes too hard to machine in economical production regardless of subsequent heat treatment. In fact, when this

steel is forged at temperatures of 2250° F., it is impossible to machine it on the production lines, as the machines cannot be operated at sufficiently low speeds for the tools to hold their cutting edges a reasonable period of time.

An interesting, but unexplained, difference in microstructure is another result of our new practice. Two micros presented herewith are examples. They are taken from the same bar of 1.00% carbon steel. One end was heated to an unknown but rather high temperature in the old oil-fired furnace about 18 months ago, forged and given the specified heat treatment, and then laid away for reference. The other end of the bar was recently heated in our present improved equipment to 1905° F., forged in the same dies, and the forging heat treated in the same way as the other end, namely quenched from 1650° F. and annealed at 1300° F. By this means it is seen that the principal variable (if not the only important one) is the method of heating before forging.

Variation in Microstructure Due to Variation in Forge Fire



Higher, exact degree unknown	Forging temperature	1905° F.
Old, slot type	Furnace	New, slot type
Oil	Fuel	City gas, luminous flame

Forgings From Opposite Ends of a 1% Carbon Steel Bar; Both Quenched From 1650° F. and Annealed at 1300° F.

It will be observed that the higher forging heat is parent to a structure which is rather coarse, well-developed pearlite, with a considerable quantity of free carbide. This micro shows no ingotism or evidence of overheating. The lower forging heat is parent to a structure which was probably uniform martensite after the quench, with little or no free carbide. The subcritical anneal has transformed this to sorbite, and the precipitated carbide particles are well dispersed along the crystallographic planes that formerly marked the needle-like structure of martensite.

These facts are representative of a mass of observations and are presented as facts without any attempt at an explanation. In fact, no logical explanation has as yet been suggested as to why the heat treated structure should be so greatly affected by the forging heat.

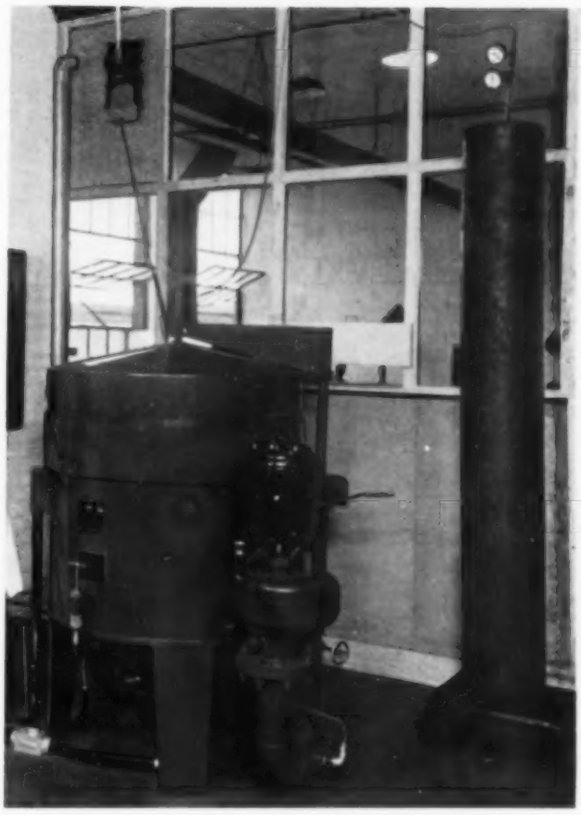
A few data on the present set-up may be useful: The luminous flame burner has a 12-to-1 turn-down. The furnace has been successfully operated as low as 1000° F., and could be run up to the limit of the refractory material. The fuel required to heat this forge from cold to 1850° F. is 2150 cu.ft. of gas, and to 2200° F. is 3000 cu.ft. The standby loss at 1850° F. is 480 cu.ft. per hr. and at 2200° F. is 600 cu.ft. The gas supplied is carburetted water gas of 530 B.t.u. per cu.ft. The average daily consumption of gas operating at 2200° F. is 9500 cu.ft. The gas fire costs 63¢ more per day than the oil fire when taking into consideration the cost of pumping the oil and the maintenance of the oil system. Gas costs 60¢ per 1000 cu.ft.; oil costs 6¢ per gal.

In summary, the luminous flame in this insulated gas-fired forge is producing an improved product, in line with better hammers and forging machines, for the superior forgings demanded by the mechanical engineer in the past few years.

Preparation of Furnace Gases for Non-Oxidizing Atmospheres

By Ernest E. Thum

Editor, Metal Progress



Small Furnace for Heat Treatment in Controlled, Circulated Atmosphere—in This Case, Nitriding at the Plant of Pump Engineering Service Corp.

WE METALLURGISTS engaged in heat treatment and utilization of metals like to think that we are not very much concerned with the problems of the men who smelt the metal from ore. However, the very modern problem of heat treatment of steel in controlled atmospheres is a process requiring an understanding of the same chemical reactions which go forward in the iron blast furnace. Some rather advanced physical chemistry is involved in that all of the reactions which go on at the surface of hot metal involve a dynamic approach to equilibrium together with certain "catalytic actions" (a handy name!). Likewise, some advanced physics and unknown considerations in physical metallurgy apply to the diffusion of elements in solids — notable in carburization or decarburization of iron during heating. Obviously, surface reactions, one or two atoms deep, would be innocuous as far as practical applications are concerned; only as deep-seated elements can diffuse to the surface and there react, or vice versa, are surface problems acute.

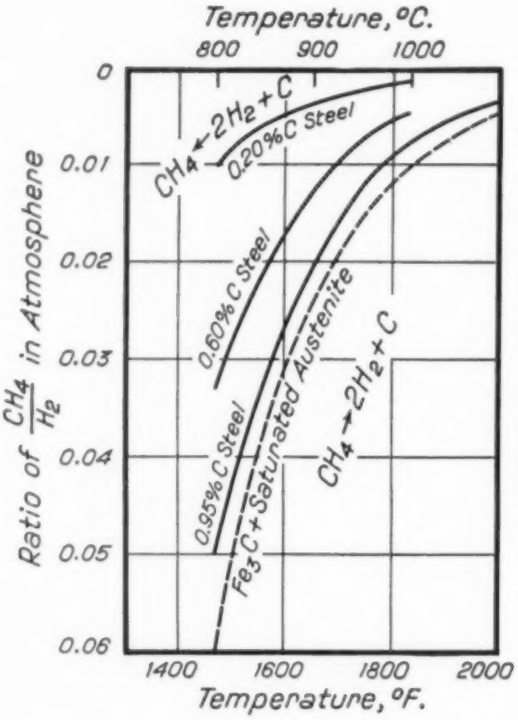
The subject is a very large one, including ferrous and non-ferrous practices. Consequently, it will be necessary to limit this article to the heat treatment of steels. Furthermore, temperatures will be limited to below the critical temperatures, as for tempering, stress relief, and process anneal. This simplifies the problem largely to the control of oxidation, first, because there is very little danger of carburization or decarburization of steels below A_1. In the second place, actions below the critical temperature are somewhat sluggish (speed increases with the temperature). We can tolerate conditions which are considerably out of equilibrium if the time is relatively short, as, for instance, in cooling through a certain range of temperature.

On the other hand, some of the things which we wish to do below the critical temperature, such as a process annealing, require much time to achieve. This may counteract the advantage just stated — namely, that reactions are slow. A slow reaction for a long time may do much damage.

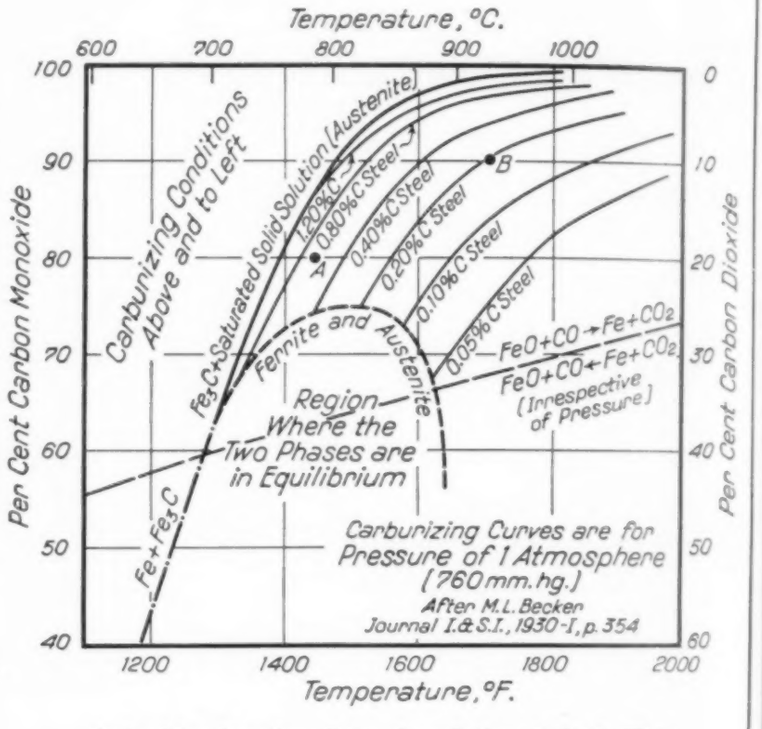
Since the ordinary atmosphere which we breathe pervades everything, even our furnaces, we must control the composition of the ambient air to control a furnace atmosphere. Air consists of about 20% oxygen and 80% nitrogen with a little carbon dioxide and more or less moisture. This atmosphere itself is quite reactive. Oxygen combines with iron even at room temperature. Neglecting, for purposes of simplification, the various iron

Equilibria for Gas-Steel Reactions

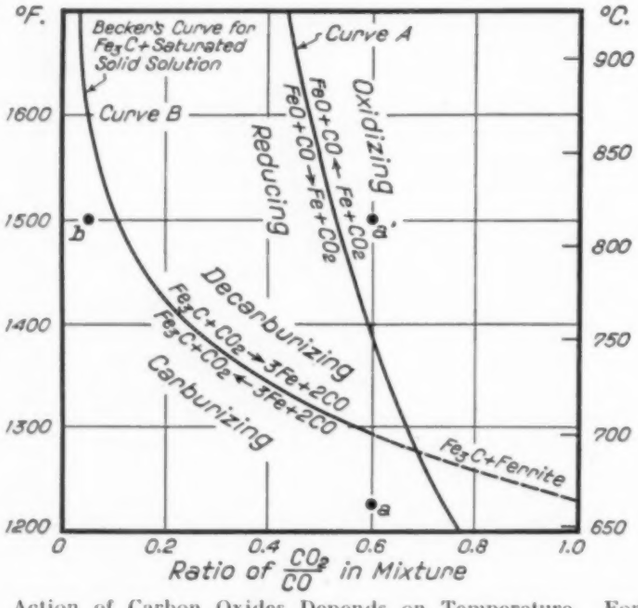
Relation Between Gas Composition, Temperature, and Carbon Content in Steel



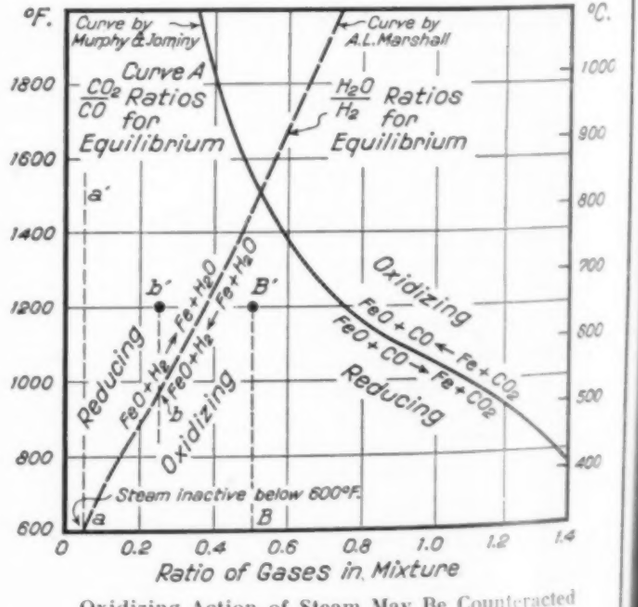
Above Curves, Adapted by Stansel From Sykes' Work, Indicate That Almost Pure H_2 Decarburizes Hot Steel (Conditions Above and Left of Corresponding Curves). Methane breaks down almost completely into carbon and hydrogen, carburizing steel (and depositing excess soot) at conditions below curves



Carburizing Reactions Depend on Carbon in Steel. Thus: 80% CO, 20% CO_2 at 1450° F., (point *A*) will carburize 0.40% C steel and lower, but decarburize 0.80% C steel and higher. However 90% CO, 10% CO_2 at 1700° F., (point *B*) is relatively inert to 0.20% C steels, will carburize lower carbon and decarburize higher carbon steels. Partial pressures, i.e., $CO + CO_2 < 100\%$, raise curves and shift to left



Action of Carbon Oxides Depends on Temperature. For instance, a dried atmosphere containing 6% CO_2 and 10% CO or ratio 0.6 (easily secured by partial combustion of fuel gas) would tend both to reduce and carburize at a 1225° F. anneal (Point *a*), but would both decarburize and oxidize at 1500° F. (Point *a'*). For "bright hardening" the CO_2 must be reduced well below Curve *B* (for instance, 1/10 the CO, as Point *b*, at 1500° F.). The above statements neglect the fact that the pressure of $CO + CO_2$ is less than 1 atmosphere



Oxidizing Action of Steam May Be Counteracted by 20 Times As Much Hydrogen (Line *a-a'*). Larger proportions of steam may scale the metal during cooling (line *b'-b*). Oxidizing — and decarburizing — propensities of moist gas may likewise be counteracted by carrying excess CO in the mixed carbon oxides present in the furnace atmosphere (for instance, $CO_2 : CO = 0.5$, or line *B-B'*, on the reducing side of curve *A*)

oxides which might form, we can symbolize this reaction in the equation

$$2\ Fe + O_2 \rightarrow 2\ FeO.$$

A little moisture or water vapor is necessary for this reaction to go forward even at room temperature. The reaction is also theoretically reversible—that is, there is a tendency for the iron oxide to revert to iron, but this requires very special and artificial circumstances as in a blast furnace, to be much more than a **tendency.** The reaction as shown, which generates heat, will proceed at any moderate temperature until either all of the iron is consumed (if time enough is given), or, if there is a limited amount of oxygen available, until practically all of the oxygen is consumed.

Note again that **time** is a necessary factor in this reaction even at moderate temperatures. This is well known from the common experience with temper colors—which are oxide coatings of increasing thickness. A faint yellow temper color will form in 8 min. at 460° F.; however, if the steel is not heated to 460° F., but only to 370° F. and left there for an hour, the same faint yellow temper color will be the result. This brings us to state the first general rule concerning controlled atmospheres, and that is this, that a bright steel will not tint nor oxidize in dry air below 350° F. for a long time. Or, put in another way, if, on cooling, the atmosphere is protective down to 350° F., the metal can then be taken out and exposed to the ambient atmosphere without damaging it.

There may also be a useful distinction between tinting or tarnishing and scaling, and a general statement may also be made that no scale will form in a reasonable time below 1100° F.

Following the above thoughts to a logical conclusion, we may say that to avoid coloration and scaling on hot iron there must be **no** free oxygen (O_2), atomic oxygen (O), nor any gas containing oxygen rather loosely bound. That brings us to the main problem of controlled atmospheres, and that is how to get rid of oxygen in this ever-present atmosphere of ours.

Flue Gases Are Too Reactive

The old-timer tried to do it by adjusting his furnace flame; that is, he tried to **burn** it out. Really all he could do was to fix it as one of the gaseous carbon oxides, CO or CO_2, or steam, H_2O. This was rather ineffective, for even if he could exclude the tiniest excess of combustion air, all of the fuel gases, as we will find out later, are far from inert in their action on hot iron and steel. Likewise it is practically, as well as theoretically, impossible to produce a flame where there is not **some** (even if a little) uncombined oxygen. Probably the resulting water vapor from the burning hydrocarbons (constituents of all the commercial fuels) as well as that coming in with ordinary air, is the bad actor.

At any rate, hot steel will scale in hot flue or combustion gases, either when they are in a "reducing" condition (namely burned with deficient air) or in an "oxidizing" condition (namely, burned with excess air). All that can be done in this way is to **limit** the amount of scaling, or affect the nature of the scale (whether tight or loose). The so-called practical furnace man has developed many ingenious ways of doing this in the development of his art throughout the centuries. Fortunately, also, the damaging decarburization usually proceeds at a somewhat slower rate than the scaling reaction, so it is possible to quench high carbon steel from an uncontrolled atmosphere and still get hard surfaces. This is fortunate, but does not vitiate our main conclusion that it is necessary to put steel in a heated box or muffle and have a special atmosphere inside in order to prevent rather extensive surface damage. Furthermore this atmosphere must have practically no molecular or atomic oxygen, to avoid tarnish or scale even at low temperatures.

Means to Eliminate Oxygen

How can this be done most economically in practice?

We can, of course, remove the oxygen from the air by liquefying the air, then putting it through a process of fractional distillation, withdrawing therefrom the relatively pure nitrogen for our purposes. However, this method of making nitrogen, although it is commercial, requires a rather costly plant, and the gas would probably come to about $10 per thousand cu.ft.

While pure nitrogen serves admirably as an inert atmosphere, it has nothing in it to counteract any leak in the muffle or consume oxygen let in with the cold metal, adsorbed on its surface, or even in light oxide layers on the metal. Therefore, a little hydrogen would be ordinarily added to pure nitrogen to react with such oxygen.

Hence we arrive at more useful mixtures of nitrogen and hydrogen gas. In them hydrogen is ordinarily kept fairly low in percentage because it is considerably more costly than the nitrogen, and furthermore, rich hydrogen mixtures introduce an explosion hazard.

A very good source of the nitrogen-hydrogen atmospheres is anhydrous ammonia (NH_3), available in tonnage, and which can readily be dissociated in simple, compact equipment to a mixture of 75% hydrogen and 25% nitrogen **very** low in water vapor. However, it costs approximately $3.50 per thousand cu.ft., and therefore is usually limited to small or special work in furnaces where there is very small wastage.

It has been said that pure hydrogen will decarburize steel at heat treating temperature (especially if it contains a little water vapor, and it is almost

impossible to keep such an atmosphere free of water vapor because a little oxygen is likely to come in from a leaky muffle, through the charge door, or from reduced oxides or scale). Such an action is indicated in the first diagram on the data sheet, page 378, but need not be more than mentioned in this discussion of **non-oxidizing** atmospheres at annealing temperatures.

An obvious way to prepare a protective gas is to start with one of our gaseous fuels, which may be regarded as mixtures of simple hydrocarbons. For low temperature work, such as we are discussing, the raw gas might be used, were it not that its combustibility would introduce definite hazards, and also that several volumes of suitable gas can be prepared from one volume of fuel gas at small additional cost.

Conversion of Natural Gases

Complete equipment is available for the conversion of methane, propane or natural gas to nitrogen-hydrogen atmospheres ranging from 7% up to 14% hydrogen. It is said that large equipment making an atmosphere of 7% hydrogen and 93% nitrogen for bright annealing of steel strip is operating at a cost of 20¢ per thousand cu.ft., but this might readily be doubled on a smaller installation. In this operation the fuel gas is burned with a deficiency of air, and then the carbon monoxide existing in this hot gas is changed to carbon dioxide by a proper catalyst. This gas is then cooled and most of the moisture taken out. Then the carbon dioxide is absorbed in an organic liquid solvent. The remaining traces of carbon dioxide may then be absorbed with caustic, and the gases dried bone dry with activated alumina. This will give a gas which contains no detectable oxygen and less than 0.5% of carbon monoxide. The organic chemical solvent may be regenerated in a separate vessel merely by heating it mildly and driving off the dissolved carbon dioxide.

This method requires a considerable chemical plant with solvent recovery equipment, heat interchangers, and so on, for economical operation, and supervision by men of rather high quality. Its countervailing advantages are that low hydrogen avoids any danger of explosion and decarburization, and yet absorbs any oxygen getting into the container, either from gases dragged in or remaining on the surfaces of the metal. Its low content of water is especially advantageous.

In such an atmosphere as this, the nitrogen can be looked upon as substantially inert, and the only reactive gas is hydrogen (and casual moisture). With the hydrogen there are two principal reactions to consider, one the reaction between hydrogen and iron carbide to form methane and pure iron, but, as remarked at the outset, either carburizing or decarburizing takes place at a practically zero rate below the critical. The other reaction, neglecting again the various kinds of oxide which will form, can be typified as follows:

$$H_2 + FeO \rightleftarrows Fe + H_2O$$

This reaction has been studied by Marshall and others in the General Electric Laboratory at Schenectady, and their results are shown by the dotted line in the lower right diagram on page 378.

This diagram is intended to be typical rather than precise. Equilibrium conditions will vary as to the oxides present, whether FeO, Fe_3O_4 or Fe_2O_3, and the line as shown may be taken as the center of the band of indefinite width within which the reactions are slow and a "practical equilibrium" attained. In other words, rapid reactions take place in heat treating atmospheres, the compositions and temperatures of which, as indicated, are some distance from the lines themselves.

It shows, among other things, that when annealing at higher temperatures, say 1000° F. and up, no scale will be formed on the hot steel surface if there is three times as much hydrogen as water (Line **b-b'**). On the other hand, when cooling to a lower temperature the conditions become oxidizing for that particular gas mixture. Hydrogen must be increased very considerably in percentage to avoid scaling or tinting. Fortunately action is so slow below 600° F. that it can be disregarded, but even so the curve indicates that if there is more than one-twentieth as much steam as hydrogen in the mixture, the bright steel on cooling will be oxidized at temperatures slightly above 600° F. Hence the necessity for starting off with dry gas so that even when the hydrogen reacts with casual oxygen, the resulting steam will amount to no more than 5% of the hydrogen. If, by any chance, this proportion increases, the steel will come out scaled superficially, or along the edges of the coil, unless definite means is taken to cool the mass rather rapidly across the lower corner of the diagram (thus shortening the time element very materially).

This matter of **moisture** in the gases has been neglected in many furnace operations, even in controlled atmospheres, probably because it is very difficult to estimate. The ordinary Orsat apparatus for gas analysis tells us nothing about moisture content. Likewise, great care must be exerted in avoiding reaction between the moisture and the sampling tube, and also to avoid losses through condensation, as the gas is cooled between the furnace and the analytical equipment.

It results that the best way of estimating moisture at the present time is by finding out what its dew point is. The dew point of an atmosphere (or any mixture of gases containing water vapor) is that point where the partial pressure of steam or vaporized water in the gas is equal to the vapor pressure of water at that particular temperature. The vapor

pressure of water increases very rapidly with temperature and is very low at low temperatures. That is merely another way of saying that hot air will take up and hold a great deal of water as a true gas, but cold air will hold hardly any. Definite figures are given in the attached table.

The method used by the U. S. Weather Bureau to determine the dew point is to take the temperature of two thermometer bulbs, one of which is bare and the other covered with damp cloth. The atmosphere being tested is blown upon these two bulbs, and if it is less than saturated, a certain amount of evaporation will take place from the moist cloth; this will abstract heat and cause the wet bulb to read somewhat lower than the dry bulb. From appropriate tables, the dew point, relative humidity and absolute humidity (or amount of moisture in unit volume of air) may then be determined.

A rather simpler method utilizes a small mirror having a micro-thermocouple fixed to its surface and so arranged that the back of the mirror can be cooled by a controlled stream of compressed gas. This compressed gas absorbs heat on expanding, and its temperature and that of the mirror are lowered. The face of the mirror is bathed in the gas under study, and one can readily see when it is clouded over with a fog of condensing water. The temperature of the surface of the mirror is then read by the thermocouple, and this gives a direct determination of the dew point.

Another piece of equipment indicates continuously a rough measure of the content of the atmosphere in hydrogen and in water. It so happens that both of these gases have a high heat conductivity, three or four times that of the other common constituents of the furnace atmosphere, and if precautions are taken to keep the moisture low, this instrument, which measures continuously the heat conductivity of the gas, will give an idea of the hydrogen present. If the hydrogen is known fairly accurately, the amount of moisture which is there will be indicated and this, as pointed out above, is very likely to be the bad actor.

Water Vapor in Air or Gas

Dew Point °F.	Gage Pressure Equivalent*	Weight of H_2O Vapor Grains/Cu.Ft.	Weight of H_2O Vapor Lb./Cu.Ft.	H_2O Vapor, % by Volume
−28	1075	0.147	0.000021	0.0367
−24	915	0.175	0.000025	0.0441
−20	725	0.217	0.000031	0.0552
−16	600	0.266	0.000038	0.0682
−12	500	0.315	0.000045	0.0817
− 8	400	0.385	0.000055	0.1005
− 4	340	0.455	0.000065	0.1195
0	285	0.540	0.000077	0.143
4	235	0.643	0.000092	0.173
8	195	0.770	0.000110	0.208
12	160	0.910	0.000130	0.248
16	135	1.080	0.000154	0.279
20	113	1.275	0.000182	0.353
24	97	1.510	0.000215	0.420
28	76	1.785	0.000255	0.502
32	60	2.10	0.000300	0.597
40	43	2.83	0.000405	0.818
50	25	4.06	0.000580	1.195
60	14	5.73	0.000820	1.72
70	5	7.98	0.00114	2.44
80	0	11.00	0.00157	3.43
90	.	14.85	0.00212	4.72
100	.	19.70	0.00283	6.4
110	.	26.40	0.00377	8.68
120	.	34.50	0.00493	11.55
130	.	44.60	0.00637	15.20

*Gas compressed and condensate removed at 80° F. All measurements based on atmospheric pressure.

So much for the discussion of hydrogen-nitrogen atmospheres for controlled heat treatment. We now take up the most popular method of controlling oxygen in the furnace atmosphere, which is an adaptation of the expedient used by the old-time furnace man—namely, take out as much of the oxygen of the air as possible by burning fuel with deficient air (say half that necessary for complete combustion), dry or otherwise treat the complex resulting gas and use it in our furnace enclosure.

All of the common fuel gases are available for this purpose and have been so used. City gas costs about $1.00 per thousand cu.ft.; while its composition is variable, it is likely to contain roughly about 50% hydrogen, 25% methane, and 15% carbon monoxide. Producer gas at 15¢ per thousand cu.ft. is also suitable; it may contain 10% hydrogen, 3% methane, 20% carbon monoxide, and 7% carbon dioxide, balance nitrogen. Furthermore, there is natural gas at 50¢ per thousand cu.ft., it being principally methane. The prepared gases such as butane or propane serve excellently.

On the above basis of incomplete combustion of city gas with three volumes of air, we get a dried mixture with about 6.5% carbon monoxide, 6.5% carbon dioxide, 9.5% hydrogen, and the balance nitrogen, and such a gas can be prepared for about 35¢ per thousand cu.ft. Natural gas is the more popular, which can be burned with six volumes of air to produce approximately 10% carbon monoxide, 6% carbon dioxide, 10% hydrogen, and perhaps 2% methane (CH_4). This gas can be prepared for approximately 10¢ per thousand cu.ft.

Either of these combinations with a moderate amount of drying to precipitate the excess moisture will not affect low carbon steel very much below the A_1 temperature. It is easy to dry this material to a point where oxidation by steam does not need to be considered with reasonably good furnace design and operation, but the use of such

a gas does bring in the equilibrium between iron, iron oxide, carbon monoxide and carbon dioxide. Before presenting some theoretical considerations along this line, the practical rule may be stated that almost any fuel gas burned so as to have about one and one half times as much carbon monoxide as carbon dioxide will be satisfactory for sheet steel annealing under cover if it is properly dried before using.

The equilibrium curves for the iron and carbon oxides shown in the lower left diagram on page 378 are adapted from Stansel's book on Industrial Heating Furnaces. It turns out that carbon monoxide is an easily oxidizable gas (like hydrogen) and therefore it takes oxygen away from metal oxide if the temperature is sufficient to expedite such a reaction. It will be remembered, of course, that these rather complex gas atmospheres that we are discussing now contain both the carbon oxides and hydrogen and its oxide, and it may perfectly well be that the one pair would tend to act in one direction pulling against the other, so to speak. However, both carbon monoxide and hydrogen can be looked upon as reducers at annealing temperatures, carbon monoxide being on the whole a more effective reducer at the lower temperatures, say below 1475° F., whereas hydrogen is more effective at higher ones.

Curve A in the lower left diagram, which is the same as Curve A in the lower right, and the dotted straight line in the upper right diagram (page 378) indicate the approximate equilibrium condition. The field at the right marked "oxidizing" merely means that at gas ratios and temperatures represented by that field the trend will be as indicated by the reaction on the right of Line A — namely, iron will react with carbon dioxide existing in such a mixture to form iron oxide and carbon monoxide. Of course, such a reaction disturbs the ratio between carbon dioxide and carbon monoxide in a closed container, and as the reaction progresses with the production of scale, the carbon monoxide also builds up, moving the composition of the gas toward the left, and soon one might get to a place where the action would cease. This, of course, would be true only in stagnant atmospheres or when a limited supply of gas of oxidizing propensities was seeping through the furnace. If a steady stream of gas containing say equal parts of CO_2 and CO (ratio 1.0) were passing through, the conditions would tend to oxidize steel at any temperature.

On the other hand, conditions existing on the left of Curve A are such that any iron oxide existing would tend to be reduced by the excess of carbon monoxide in the atmosphere with the production of metallic iron and some carbon dioxide.

Curve B to the same scale indicates conditions which tend to carburize or decarburize, as the case may be. It is of most importance in heat treating at higher temperature than annealing, so its detailed consideration should be deferred to a later article on "bright hardening." Here only a few generalities concerning this curve can be presented.

Consider a mixture of 6% carbon dioxide and 10% carbon monoxide, such as results from partial combustion of natural gas. At 1225° F., the temperature of a process annealing, we will find the location of such a mixture (CO_2:CO = 0.6) to be well below and to the left of both Curves A and B at the working temperature (Point a). In other words, this gas has a reducing tendency and a definitely carburizing tendency (even though the temperature is too low for the carburizing action to be active). The practical program for sheet steel annealing at low temperatures, therefore, is to have gases which are well to the left of Curve A so that they will be in the reducing (non-oxidizing) region, and dry enough so that the steam will not scale them during the cooling after the fairly long time at recrystallization temperature.

Simple Units for Gas Preparation

Many of the furnace builders have put on the market gas preparation units to convert fuel gas into adequate atmospheres for sheet steel annealing. These mix the gas and air in measured quantities and burn them in a combustion chamber, pass the hot gases through a heat interchanger and then generally into a scrubbing and cooling tower where they come in contact with water sprays which reduce the temperature to about 100° F. From here they go through another tower where most of the water involved is trapped, and then on into the heat interchanger noted before where they are warmed prior to entrance into the furnace.

In some instances, such gases, simply prepared and saturated at 100° F., would contain so much moisture as to tarnish material during the cooling cycle. Under those circumstances, the partially dried gases would be further dried by sending them through a refrigerating coil (operating like an overgrown domestic refrigerator) and then through a fog trap before going to the heat interchanger and to the furnace itself. In some instances it is found more economical to condense out this excess moisture by compressing the gas rather than by cooling it, but this is a minor detail and decision would depend upon local circumstances. Sometimes it might even be desirable to really dry the gas with activated alumina.

Enough has been said to indicate the reason why a reasonably dry gas carrying an excess of CO over CO_2 is a satisfactory one for bright annealing of steel. Oxidation is only to be prevented. At higher temperatures, where carburization and decarburization have also to be under control, the situation is much more difficult, but that must be treated in a subsequent article.

Properties of Refractory Materials, Except Fireclay

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Material (1)	Composition of the Pure Material		Melting Point	True Specific Gravity	Hardness (Moh's Scale)	Mean Specific Heat (17)	Thermal Expansion (Note 22)	Thermal Conductivity (2)		
	Formula	Composition %						At 1000°F.	At 1600°F.	At 2400°F.
Andalusite	$Al_2O_3.SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810°C. 3290°F.	3.20	7.5	0.168 (18)	6.2*			
Chromite	$FeO.Cr_2O_3$ (3)	Cr_2O_3 68 FeO 32	2180°C. 3956°F.	4.5	5.5	0.22*	8.0*	10.0*	10.9*	12.1*
Corundum	Al_2O_3	Al_2O_3 100	2050°C. 3722°F.	4.0 (24)	9	0.304*	8.5	23.0*	26.5*	30.0*
Cyanite (Kyanite)	$Al_2O_3.SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810°C. 3290°F.	3.6 ±	4 to 7		4.9* (4)			
Diasporite (Diaspore) (5)	$Al_2O_3.H_2O$	Al_2O_3 85.1 H_2O 14.9	2050°C. 3722°F.	3.4 to 3.5	6.5 to 7	(Note 6)	6.5*			
Dolomite	$CaCO_3.MgCO_3$	CaO 30.4 MgO 21.9 CO_2 47.7	(Note 23)	2.81 to 2.95	3.5 to 4.0	0.222 (19)	14.0			
Dumortierite	$8Al_2O_3.6SiO_2.$ $B_2O_3.H_2O$	SiO_2 64.6 Al_2O_3 28.5 B_2O_3 5.5 H_2O 1.4	1810°C. 3290°F.	3.30	7		5.2*			
Forsterite	$2MgO.SiO_2$	MgO 57.3 SiO_2 42.7	1910°C. 3470°F.	3.22	6 to 7	0.22 (19)	10.5*	11.1*	10.6*	10.3*
Graphite	C	C 100	>3000°C. >5432°F.	2.25	1 to 2	0.29	2.2			
Magnesia spinel	$MgO.Al_2O_3$	MgO 28.2 Al_2O_3 71.8	2135°C. 3875°F.	3.6	8	0.257	8.5	12.2*	13.3*	14.5*
Mullite	$3Al_2O_3.2SiO_2$	Al_2O_3 71.8 SiO_2 28.2	1810°C. 3290°F.	3.03		0.175 (20)	5.3 (7)			
Periclase (Magnesia) (8)	MgO	MgO 100	2800°C. 5072°F.	3.64 to 3.67	5.5 to 6.0	0.285	13.5*	19.5*	15.5*	13.0*
Quartz (9) (Quartzite)	SiO_2	Silica 100	1400°C. (10) 2552°F.	2.653	7	0.263*	32.6* (11) 4.6 (12)	8.8*	10.7*	13.3*
Silicon carbide	SiC	Si 70 C 30	2250°C. (13) 4082°F.	3.17 to 3.21	9 to 10	0.19 (14)	5.2 (15)	142*	110*	80*
Sillimanite	$Al_2O_3.SiO_2$	Al_2O_3 62.85 SiO_2 37.15	1810°C. 3290°F.	3.24	6.5 to 7.5	0.175				
Zircon (Zirconium silicate)	$ZrO_2.SiO_2$	ZrO_2 67.1 SiO_2 32.9	2550°C. 4622°F.	4.7	7.5	0.132 (21)	4.5			
Zirconia (Zirconium oxide)	ZrO_2	Zr 73.9 O_2 26.1	2700°C. 4892°F.	5.5 to 6.0	6.5	0.16	6.6 (16)	12.0*	13.0*	14.0*

*1. These properties refer to pure materials and not to commercial refractories which may differ because of impurities, bonding materials, and process of manufacture. The specific heat, thermal expansion and thermal conductivity data, however, may be used for engineering purposes and especially those marked with asterisk (*) which were obtained from commercial products.

2. Thermal conductivity in B.t.u. per in., per hr., per sq.ft., per °F., averaged from the more reliable data on refractories.

3. General chemical formula for chromite is $RO \cdot R_2O_3$. The RO oxide is usually FeO and may be replaced in part by MgO, while the R_2O_3 is mostly Cr_2O_3, but may be replaced in part by Al_2O_3 and Fe_2O_3.

4. Indian.

5. Commercial diaspore is composed of diasporite grains bonded with clay.

6. Probably close to 0.26.

7. Synthetic, pure.

8. Magnesite is amorphous, or crystalline like periclase, depending upon the heat treatment it has received.

9. Ganister is the commercial form for use in refractories, about 98% silica.

10. Crystobalite is the stable form of silica above 1470° C., and has the melting point of 1713° C. (3115° F.).

11. Value is for silica brick, mean expansion in range 20 to 300° C.

12. Value is for quartz, mean expansion in range 300 to 1135° C.

13. Dissociation temperature; oxidation may begin at 900° C. (1652° F.).

14. Varies with temperature.

15. This figure, and those for thermal conductivity, are for recrystallized material.

16. Pure material sintered.

17. For the range 20 to 1000° C. (68 to 1832° F.) unless noted.

18. For the range 0 to 100° C.

19. For the range 20 to 100° C.

20. For the range 20 to 800° C.

21. For the range 21 to 51° C.

22. Values for the mean reversible thermal expansion per ° C. times 10^6, for the range 20 to 1000° C. unless noted.

23. Dissociates at very high temperatures.

24. Alpha modification.

New Types of Refractories for Openhearths

By Federico Giolitti

Bessemer Medalist

Turin, Italy

Fettling an Openhearth Furnace in a British Steel Plant. Photo by G. Marshall Smith

REFRACTORY bricks and fettling materials for openhearth furnaces have been subject to important researches during the past few years in Europe and America. Primarily on account of the different qualities of raw materials, European industrial practice, based on the results of such researches, is frequently somewhat different from American.

Silica or dinas bricks are, by far, the most commonly used refractories in European openhearths. The well-known inconveniences connected with their use, especially in basic furnaces, are usually more than balanced by their relatively low price, owing to the wide distribution of good silica rock for their manufacture. For many years, our best dinas bricks were made from German and Czechoslovakian quartzites. Lately excellent results have been obtained with French, Italian and Spanish sandstones. The recent development and wider application of "black dinas" bricks (made of crystalline quartzites of very different qualities) has still further improved the resources in raw materials for refractory manufacture.

European practice for the manufacture of black dinas varies within wide limits. The proportion of CaO is generally between 1.2 and 2%. The percentage of ferrous slag may vary within wider limits, on account of the larger range of its composition, but it is usually somewhere between 1 and 2%. Charcoal or coke powder is generally used to about 1.25 to 1.60% as a reducing agent.

Notwithstanding their somewhat lower melting point, black dinas bricks usually give very good results, provided some caution is used in starting the furnace. When properly used, these bricks stand a greater number of heats, in most of the European furnaces regularly using them, than normally expected with the best regular silica brick.

A new type of silica brick has been manufactured in northern Spain under the name "Agata," using a rock for raw material having a chemical composition similar to that of agate, that is, silica containing small percentages of iron oxide. The quality of these bricks is, I believe, considerably *(Continued on page 402)*

THE LARGEST "CIRC-AIR"

THE largest "Circ-Air" furnace built thus far is illustrated. Heating chamber is 7½' wide, 40' 9" long and 20" clearance. Capacity is 8000 lbs. per hr. of aluminum heated to 1050 deg. F. or 16,000 lbs. per hr. of steel heated to the same temperature. Twin fans recirculate 28,000 cu. ft. per min. of hot gases. Utilizing the patented "Circ-Air" principle of recirculation and method of passing hot gases through the work, accurate temperature control and extremely uniform heating is secured regardless of variations in loading of work on conveyor up to maximum capacity.

Numerous other "Circ-Air" units are being used for the tempering of steel parts; heat treating aluminum; annealing or coloring of brass; bluing of steel parts; and other operations from 250° to 1350° F.

Send for bulletins No. 5 and 6 containing further details.

INDUSTRIAL HEATING EQUIPMENT CO.

Manufacturers of Industrial Furnaces and Oil Burners Since 1917

3570 BELMONT PLACE DETROIT, MICH.

Refractories

(Cont. from page 384) superior to that of any other silica brick commercially produced at present in Europe. Their softening point lies above 1750° C., their specific gravity is lower than 2.35, and their coefficient of thermal expansion is much lower than that of any other commercial silica brick.

Magnesite bricks are ordinarily used in Europe only for bottoms of hearths and for the lower part of walls, below the slag level. Unburned magnesite bricks are generally preferred. Some of the proprietary types of magnesite, or magnesite-chromite bricks marketed in America (as, for instance, "Metalkase," "Ritex," "Radex," "Forsterite") are rarely used in Europe. On the contrary, more and more chromite and chromite-magnesite bricks of other classes are consumed in European practice.

A comparatively new type of chromite-magnesite brick, the use of which is expanding rapidly, is "Siemensit," made from the molten slag produced in the manufacture of low carbon ferrochromium by the Haglund process. The raw materials used are chromite, magnesite and bauxite; the bricks contain about 35% Cr_2O_3, 25% MgO, and 35% Al_2O_3. Their interesting properties are a very high melting point (above 2000° C.), and a high resistance to the chemical action of either acid or basic slag. Exceptionally good results have been obtained with these bricks in openhearth furnaces heated by coke oven gas, running at very high temperatures.

Zircon bricks are seldom used (notwithstanding their excellent physical properties) on account of their poor resistance to the chemical action of slags.

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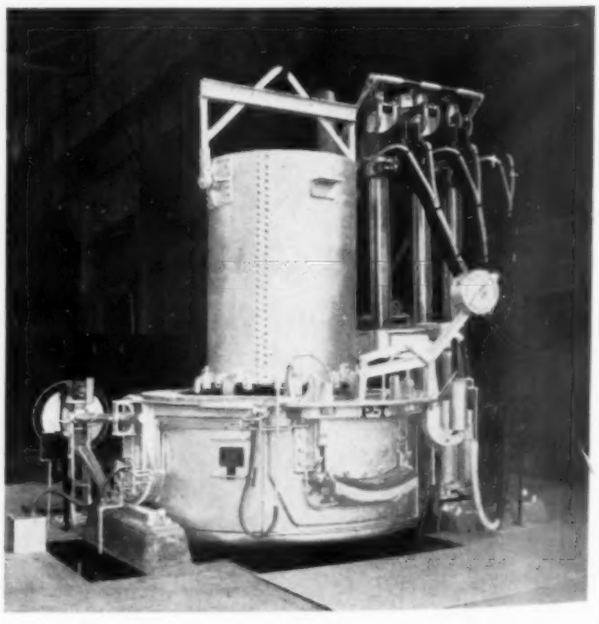
Copper and Nickel and Alloys
Ferro-alloys, Carbide, and Special products.

Furnaces available in top-charge type with quick raise and swing roof — also in door-charge type.

RAPID — ECONOMICAL — RUGGED

The illustration shows a top-charge type LECTROMELT furnace being charged by a crane handled, drop bottom charging bucket. Note that the roof has been raised and swung aside for top charging.



Built in Standard Sizes from 25 Pounds to 50 Tons Capacity

PITTSBURGH LECTROMELT FURNACE CORP.

Foot of 32nd Street, Pittsburgh, Pa. — P. O. Box 1257

Improvements in Forging Methods

By Adam M. Steever
Superintendent
Columbia Tool Steel Co.
Chicago Heights, Ill.

Photo by Caxton at Cleveland Tractor Co.

1937 HAS BEEN one of expanded output in forging and pressing, improved technique, and added and improved equipment rather than one of development in new directions. Since other sections of this volume will cover the testing, control, raw materials and their applications, these comments will refer more or less to the demands on the forging industry and the actual operations of preparation for forging, forging itself and the resultant product.

Sizes of forgings run from a needle to a 16-in. gun. Except for greater armament requirements the current needs are about the same as they have been, with a large percentage of the work flowing to the automobile industry.

Large purchasers are demanding close tolerance in dimensions. This in turn has hastened the obsolescence of inaccurate and inefficient equipment, representing a requirement for new improved facilities to meet these demands.

With interchangeability of finished parts has come an improvement in quality of product, in accuracy of finished surfaces, and in fits in gaging devices to detect variations in thousandths of an inch. It is logical, therefore, that the specifications for forgings, from which these parts are made, have demanded closer tolerances with regard to the size, structure and weight.

Producers of forgings have met these demands by improving their methods of manufacture, adopting modern equipment and establishing more frequent inspection in processes. In so doing they have progressed in finding means to accomplish these objectives. Realizing a definite economic need for the establishment of commercial tolerances, the Drop Forging Association adopted a set of standard tolerances for forgings during the year 1937 (see the data sheet on the next page).

Forging Equipment

Decreasing ranges of acceptable variation in forging dimensions have been met by the installation of new and heavier forging equipment. A few years ago hammers were constructed to dissipate the forces of impact by allowable movement of the structural elements guiding the hammer ram. Tie bolts with springs permitted considerable motion, so much that slot-

Standard Tolerances for Forgings up to 100 Lb.

Adopted by Drop Forging Association, 1937

TOLERANCES, within the scope of these standards, shall be either "special" or "regular."

Special tolerances are those particularly noted on the drawings or in the specifications, and apply only to the particular dimension or thing noted. They may state any or all tolerances in any way as occasion may require. Regular tolerances apply in all other cases.

Regular tolerances in general forging practice are known as (*a*) "commercial standard," for general forging practice, or (*b*) if extra close work is desired involving additional expense and care in the production of forgings, "close standard" may be specified.

Class I—Thickness Tolerances

For drop hammer forgings, thickness tolerances shall apply to the overall thickness measured in a direction perpendicular to the fundamental parting plane of the dies.

For upset forgings, thickness tolerances shall apply to the metal actually enclosed and formed by the dies, measured parallel to the direction of travel of the ram.

Thickness Tolerances in Inches

Max. Net Weight	Commercial		Close	
	Minus	Plus	Minus	Plus
0.2	0.008	0.024	0.004	0.012
0.4	0.009	0.027	0.005	0.015
0.6	0.010	0.030	0.005	0.015
0.8	0.011	0.033	0.006	0.018
1	0.012	0.036	0.006	0.018
2	0.015	0.045	0.008	0.024
3	0.017	0.051	0.009	0.027
4	0.018	0.054	0.009	0.027
5	0.019	0.057	0.010	0.030
10	0.022	0.066	0.011	0.033
20	0.026	0.078	0.013	0.039
30	0.030	0.090	0.015	0.045
40	0.034	0.102	0.017	0.051
50	0.038	0.114	0.019	0.057
60	0.042	0.126	0.021	0.063
70	0.046	0.138	0.023	0.069
80	0.050	0.150	0.025	0.075
90	0.054	0.162	0.027	0.081
100	0.058	0.174	0.029	0.087

Class II—Width and Length Tolerances

Width and length tolerances shall be alike, and are classified in three subdivisions (*a*) shrinkage and die wear tolerance, (*b*) mismatching tolerance, (*c*) trimmed size tolerance.

For drop hammer forgings, width and length tolerances shall apply to the metal actually enclosed and formed by the die, as measured parallel to the fundamental parting plane of the dies.

For upset forgings, width and length tolerances shall apply to directions perpendicular to the direction of travel of the ram.

II(a)—Shrinkage and Die Wear Tolerances

See table below. These shall not be applied separately, but only as the sum of the two; they shall be measured in such a way as to eliminate draft or variation in draft. They apply to that part of the forging formed by a single die block, and to no dimension crossing the parting plane.

Shrinkage and Die Wear in Inches

	Shrinkage			Die Wear	
Length or Width	Commercial + or −	Close + or −	Max. Net Weight	Commercial + or −	Close + or −
1 in.	0.003	0.002	1 lb.	0.032	0.016
2 in.	0.006	0.003	3 lb.	0.035	0.018
3 in.	0.009	0.005	5 lb.	0.038	0.019
4 in.	0.012	0.006	7 lb.	0.041	0.021
5 in.	0.015	0.008	9 lb.	0.044	0.022
6 in.	0.018	0.009	11 lb.	0.047	0.024
For each additional inch add	0.003	0.0015	For each additional 2 lb. add	0.003	0.0015
For example:			For example:		
7 in.	0.021	0.011	13 lb.	0.050	0.026
12 in.	0.036	0.018	21 lb.	0.062	0.031
18 in.	0.054	0.027	31 lb.	0.077	0.039
24 in.	0.072	0.036	41 lb.	0.092	0.046
36 in.	0.108	0.054	51 lb.	0.107	0.054
48 in.	0.144	0.072	71 lb.	0.137	0.069
60 in.	0.180	0.090	91 lb.	0.167	0.084

II(b)—Mismatching Tolerance

Mismatching is the displacement of a point in that part of a forging formed by one die block of a pair, from its desired position when located from the part of the forging formed in the other die block of the pair, measured in a projection parallel to the fundamental parting plane of the dies. It does not include any displacement caused by variation in thickness of the forging; mismatching tolerances are independent of and in addition to any others.

Mismatching Tolerance in Inches

Max. Net Weight	Commercial	Close
1 lb.	0.015	0.010
7 lb.	0.018	0.012
13 lb.	0.021	0.014
19 lb.	0.024	0.016
For additional 6 lb. add	0.003	0.002
For example:		
37 lb.	0.033	0.022
55 lb.	0.042	0.028
79 lb.	0.054	0.036
97 lb.	0.063	0.042

II(c)—Trimmed Size Tolerances

The trimmed size shall not be greater nor less than the limiting sizes at the parting plane imposed by the sum of the draft angle tolerances and the shrinkage and die wear tolerances.

Class III—Draft Angle Tolerances in Degrees

	Drop Forgings		Upset Forgings	
	Outside	Inside Holes	Outside	Inside Holes
Nominal angle	7	7 or 10	3	5
Commercial limits	0 to 10	0 to 13	0 to 5	0 to 8
Close limits	0 to 8	0 to 8	0 to 4	0 to 7

Class IV—Quantity Tolerances

Any quantity shipped within the quoted limits of over-run or under-run shall be considered as completing each release or part shipment of an order. Limits are as follows:

Quantity Tolerances

Number on Order	Over-run	Under-run
1 to 2	1 piece	0
3 to 5	2 pieces	1 piece
6 to 19	3 pieces	1 piece
20 to 29	4 pieces	2 pieces
30 to 39	5 pieces	2 pieces
40 to 49	6 pieces	3 pieces
50 to 59	7 pieces	3 pieces
60 to 69	8 pieces	4 pieces
70 to 79	9 pieces	4 pieces
80 to 99	10 pieces	5 pieces
100 to 199	10%	5.0%
200 to 299	9%	4.5%
300 to 599	8%	4.0%
600 to 1,249	7%	3.5%
1,250 to 2,999	6%	3.0%
3,000 to 9,999	5%	2.5%
10,000 to 39,999	4%	2.0%
40,000 to 299,999	3%	1.5%
300,000+	2%	1.0%

Class V—Fillet and Corner Tolerances

Fillet and corner tolerances apply to all intersecting surfaces even though drawings or models indicate sharp corners. If such drawings or models have or indicate (even though actual dimensions are not specified) fillet or corner dimensions of larger radii than the following standards, such larger dimensions shall be considered as actually specified and the tolerances shall be "special tolerances."

Where a corner tolerance applies on the meeting of two drafted surfaces, the tolerance shall apply to the narrow end of such meeting and the radius will increase toward the wide end. The total increase in the radius will equal the length of the drafted surface in inches, multiplied by the tangent of the nominal draft angle.

Fillet and Corner Tolerances

Max. Net Weight	Commercial	Close
0.3 lb.	3/32	3/64
1 lb.	1/8	1/16
3 lb.	5/32	5/64
10 lb.	3/16	3/32
30 lb.	7/32	7/64
100 lb.	1/4	1/8

ted holes were used for the bolts fastening these guiding elements or frames to the head section of the hammer. Recent hammer designs confine all the forces of impact within the hammer, resulting in a practically rigid construction. This rigid construction produces more accurate forgings due to better guiding of the ram, and compensates by using fewer blows, thus increasing production.

These same features of extreme rigidity and accurate die alignment are also essential in a forging machine or forging press. These requirements have been met by builders of this type of forging equipment and considerable progress has been made by these industries during the past year.

When a forging is produced in a press having a weak structure which stretches under load during the final forging operation, the stock, following the path of least resistance, flows out between the faces of the dies in the form of excess metal or flash, rather than into the die impressions. Setting the dies closer does not solve the problem, but merely results in additional springing of the structural parts and, if carried far enough, the equipment breaks.

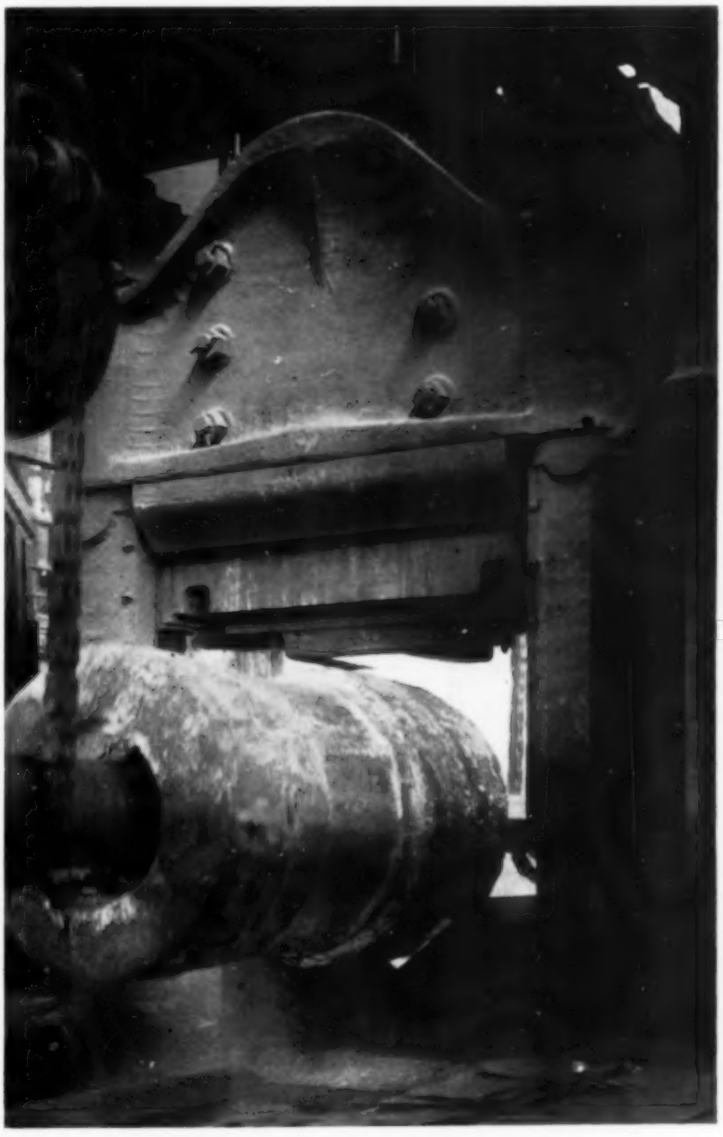
All these factors have promoted the construction of forging machines having extreme rigidity.

Heating Methods

While the comment which follows probably should fall into the equipment section, nevertheless the writer is of the opinion that the most outstanding development in forging during the year 1937 has been improved methods of heating for forging. This has required the adoption of atmosphere and automatic temperature control in the furnaces used for heating the steel billets and forged parts that depend on subsequent heat treatment for their ultimate properties.

It is becoming more generally recognized that the quality of forging work can be no better than the heating method. This trend in furnaces, therefore, is a most important one during the current year, and still appears to be an item of major concern, representing first a requirement for new equipment and second, the need for experience in the manipulation and use of atmosphere control.

To meet the increased demand for product quality, new furnace equipment is appearing in the fine steel mills for heating ingots and billets for forging. A typical installation was described by Winfield Foster in METAL PROGRESS, January 1936. It consists of a complete change-over to gas fuel, controlled temperature, controlled atmosphere throughout. During the short time the new furnaces have been in operation they have shown an added improvement in perfor-

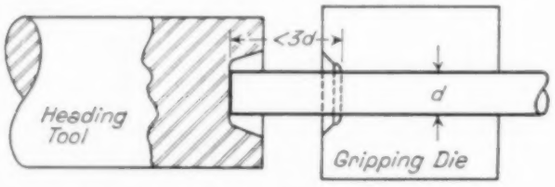


They Really Come Big Sometimes!
Photographed at The Midvale Co.

Rules Governing Forging Machine Dies

(Adapted from E. R. Frost; Courtesy National Machinery Co.)

Rule I — The limiting length of unsupported stock that can be gathered or upset in one blow without injurious buckling is three diameters.

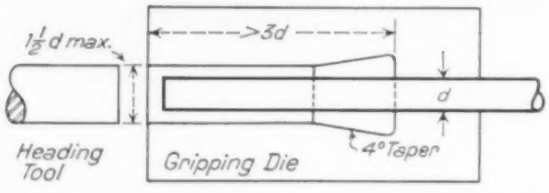


Note. (*a*): A safer maximum length is $2\frac{1}{2}d$; little attention need be paid to squareness of end if $l=2d$. If $l>3d$, buckling will occur near the middle of the unsupported length. These principles hold irrespective of whether the stock overhangs the face of the gripping dies, or whether any portion is gathered in either gripping dies, heading tool or both.

Rule II — Lengths of stock more than $3d$ can be gathered or upset in one blow provided the upset is contained in either the gripping die or a straight or slightly tapered hole in the heading tool, and the diameter of the upset made in that blow is not more than $1\frac{1}{2}d$.

Note (*a*): Multiple buckling will be checked by contact with sides of the die, and friction therewith will cause a fin to form around end of upset. Such long upsets cannot be made half in one die and half in the other, for central buckle will receive no side support.

Note (*b*): A safer maximum is $1.3d$, and if Rule I is also applied, the upset will be free from fins at the end.



Note (*c*): For very long upsets, it is helpful to have the end of the bar at a lower temperature, and to have a minimum diameter upset for the outer half of the die, the inner half tapering 4° to wider diameter at the base.

Note (*d*): In upsetting tubing, the basic dimension is wall thickness; that is, wall thickness cannot be increased more than 50% at one blow.

Rule III — For upsets requiring more than $3d$ in length of stock, and in which the upset is $1\frac{1}{2}d$, the amount of unsupported stock beyond the face of the die must not exceed $1d$ (operation 1, at right).

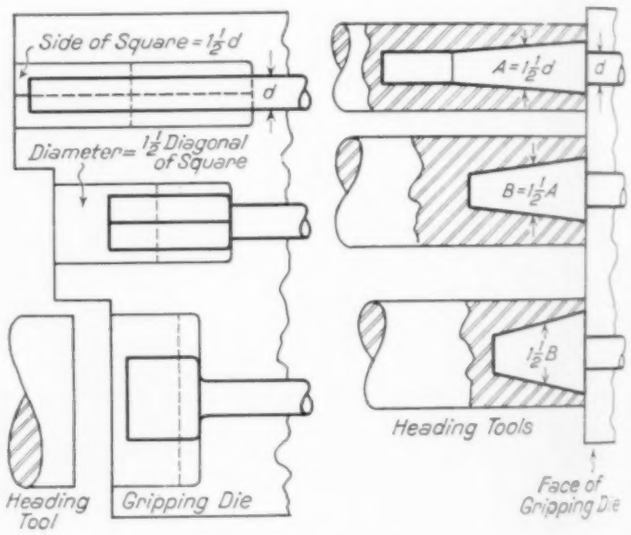
Note (*a*): Unsupported stock can amount to $1\frac{1}{2}d$ if diameter of upset is reduced to $1\frac{1}{4}d$.

Rule IV — Large amounts of stock can be gathered by multiple application of Rule II and III, and by using square or tapered impressions.

Note (*a*): In making the wide flange in sketch at left, below, the first and second impressions are within the $1\frac{1}{2}d$ limit, but the third, being a short upset under Rule I, is unlimited in diameter.

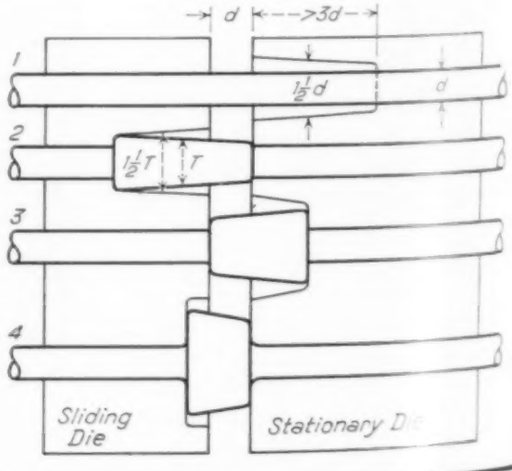
Note (*b*): The side of the square may be $1\frac{1}{2}d$ of the original bar, and the diameter of the next round may be $1\frac{1}{2}$ times the diagonal of the square.

Note (*c*): Tapered holes are proportioned as to their diameters at midlength.



Rule V — Sliding dies, for upsetting stock at some distance from the end of a bar, are governed by all the above rules.

Note (*a*): Friction along the sides of the sliding die will favor upsetting near its front end, so multiple impressions should be alternately in front and rear half, or alternately in sliding die and gripping die, as shown in sketch below.

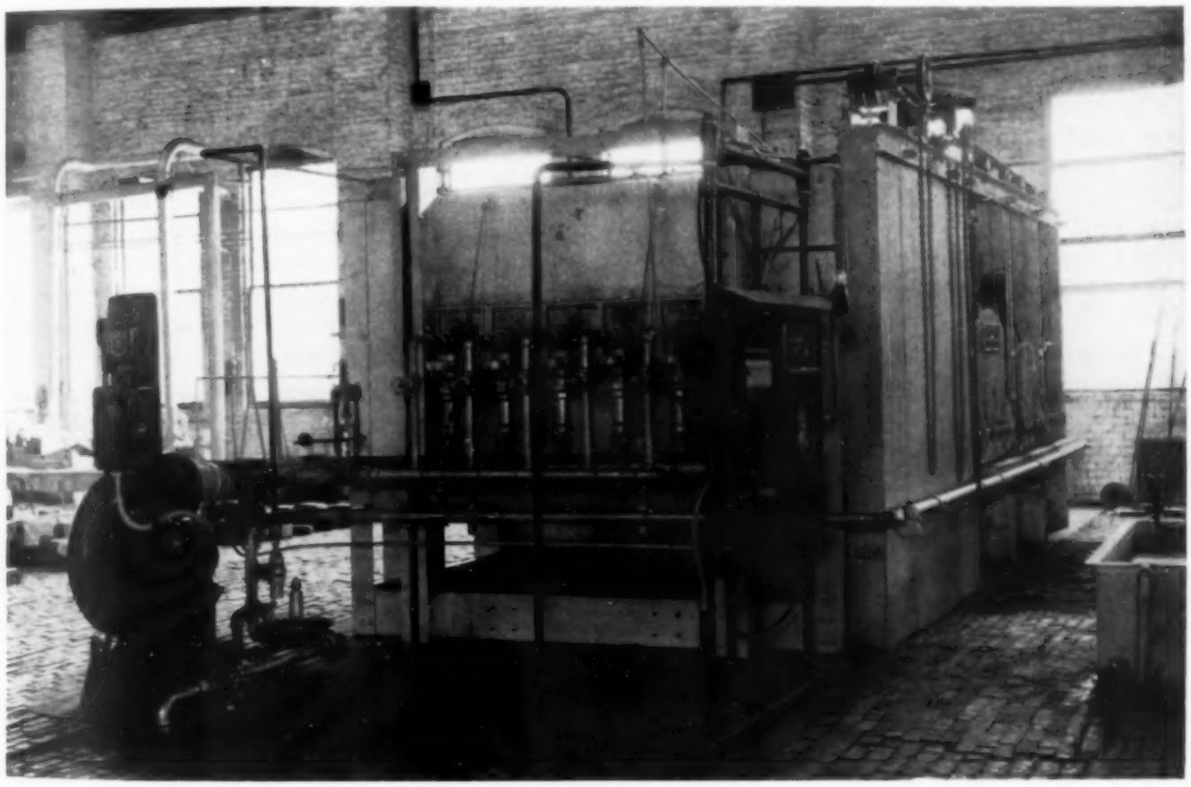


mance, including reduction in scale and in the control of surface decarburization, and thus result in a greater net return per pound of material processed. In addition, speed of heating plus accuracy of temperature control, which has come to be taken for granted on installations of this type, has further improved the quality of the finished work. These new furnaces embody improvements in combustion chamber design and in the application of burners and controls which are the fruit of additional research and experience.

Accuracy of combustion control has come about from two factors — *(a)* the availability of a supply of gas fuel of uniform heating value and *(b)* the combustion of this gas with burners producing a short flame at positive pressures within the furnace chamber, with a uniform and predetermined air supply. This practice eliminates the variables in the combustion equation.

The new furnaces shown in the illustration are of the conventional box type and are portable, since they possess a steel underframe resting on but not fixed to a concrete slab. This permits expansion and contraction, transmits a minimum of ground shocks to the furnace proper, and is expected to contribute substantially to longer life and lower repairs.

Although the overall dimensions run up to 26 ft. long by 12 ft. deep, the furnaces are designed so that they can be jacked up on rollers and moved to new locations, should plant practice make this desirable. Having no stacks, and being connected only to gas and air lines and to control instruments which are easily moved, these furnaces are truly portable.



Improved Furnaces and Heating Methods Have Not Only Increased the Thermal Efficiency, but Reduced Scale and Surface Decarburization, and Increased the Production

Such furnaces have heating chambers up to 7 ft. deep and approximately 16 ft. long with the height of door openings arranged to suit the various sizes of work to be heated. They are lined with the new super refractory firebrick (increased alumina) backed with light weight insulating brick.

In use, the heating program is an exact schedule determined by the hammer foreman. By means of a program slate he indicates his instructions for the next 24 hr. A recording

pyrometer shows whether or not these instructions have been followed and, likewise, continuous gas analysis apparatus shows whether or not desired combustion has been maintained.

It is certainly true that heating for forging is probably the most important operation for the successful production of fine forgings. Another phase of this same problem is discussed by L. E. Raymond in his article on page 375.

All steel makers and many users know too well that hardenable steels must be uniformly heated in every step from melting to heat treating if the final properties are to be uniform. The writer cannot overemphasize his belief that real control of heating is a hundred times more important than all the "personality" tests that have ever been suggested. This takes much of the selection and grading and all of the blame out of the manufacturing methods, substituting mechanically accurate regulation.

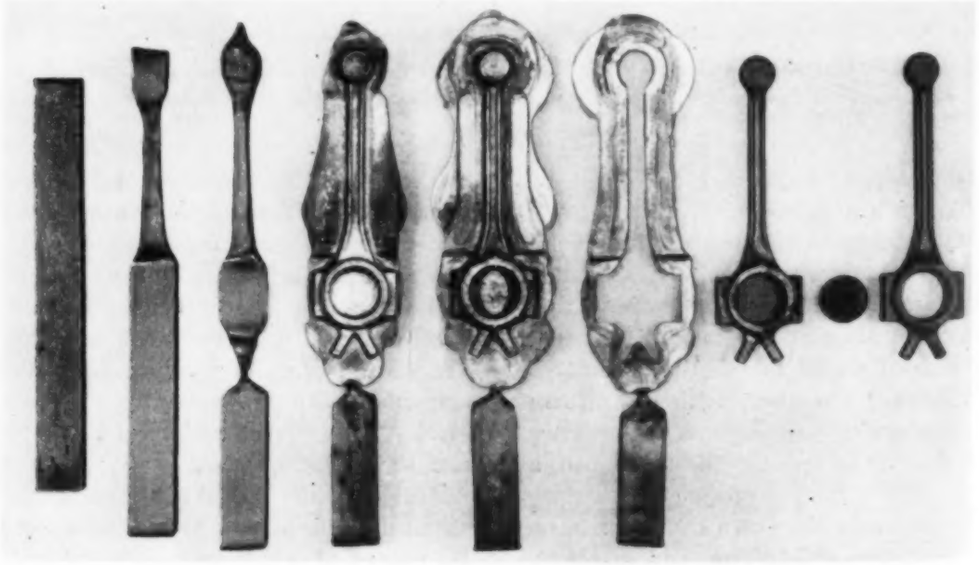
Grain Flow

Much work has been done in the control of grain flow. Proper grain flow in the finished forging is of vital importance. In order to secure maximum strength and durability, forgings should be so formed that the flow lines are in the correct position.

The physical properties of steel, particularly impact resistance, are greatly influenced by the presence or absence of this fibrous condition. As summarized by Georges Delbart in the last issue of METAL PROGRESS, physical tests made from various types of forgings, both parallel with and transverse to the direction of flow, show large differences in the impact values; high values are noted when the test piece is taken with the direction of forging so that the fracture must work *across* the grain flow or "fiber"; lower values are shown when the fracture is parallel to the fibers. Elastic limit and tensile strength are little different, but elongation and reduction of area are considerably lower on the cross grain tests — that is, when the tensile test pieces are cut with their axes perpendicular to the direction of extension in forging.

From the above it is evident that the designer of forgings as well as the forger should consider carefully the factor of grain flow in the design of forging dies and the mechanical working of the hot materials. This will produce a finished product that will be able to withstand maximum stress in service.

In conclusion, the writer is of the opinion that in the near future forging manufacture will become more automatic, due to further improvement in forging equipment, including presses, forging machines, dies and heating equipment. This can be accomplished by the close cooperation of all concerned. He is also of the opinion that the forging industry has contributed largely to the success of the automotive, farm implement, railroad, and machine-building industries, to say nothing of adding to the national security, and therefore has a secure future for continued success.

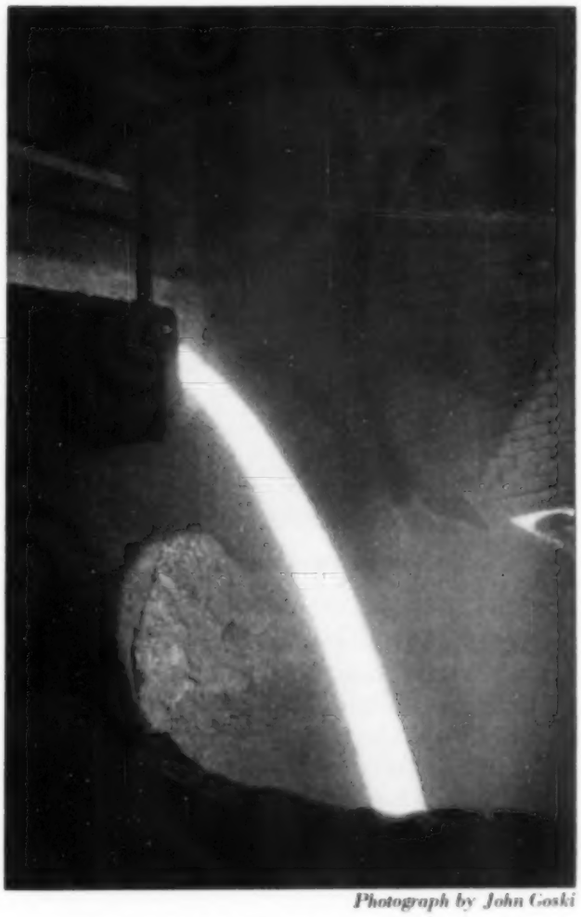


Courtesy Moore Drop Forging Co.

Various Stages in the Metamorphosis of a Bar Into a Drop Forged Connecting Rod

Advances in Carbon Steel Manufacture & Application

By Richard W. Simon
Metallurgical Assistant,
Pittsburgh District,
Carnegie-Illinois Steel Corp.



Photograph by John Coski

Good Steel Starts With the Pig Iron

THE MORE RECENT refinements in carbon steel manufacturing and processing methods have been of such importance that producers and consumers alike are viewing the future with considerable interest. Up until the last few years, there was an inclination to minimize the need for exact control in the manufacture of carbon steel, and there was probably an equal reluctance on the part of consumers to establish precise methods of processing. These conditions led to a definite limit of usefulness for the carbon steels and consequently promoted the application of alloy steels wherever industry required a better product. Demands for long life at high and low temperatures, equal strength and toughness with decreased weight, and high fatigue values under severe service are typical of recent alloy steel requirements. Fortunately this situation is being splendidly met by many refinements in alloy practice.

However, the requirements of low cost production have frequently dictated that an improved carbon steel, at lower cost, be substituted in what formerly was considered as an alloy application. The carbon steel of a few years ago was not uniform enough to stand up under these new specifications, but steel producers are currently meeting the need for a better steel through consistent and purposeful refinements in manufacture. They likewise are ready to praise the engineers and shop men in steel consuming industries who, through many improvements in processing methods, have been able to meet the public's increasing demand for stronger, more powerful, and lighter automobiles, tools or machines at less cost. These men have attained their goal in part through developing finer methods of heat treating, forming, machining and testing to get the most from the steels at hand. Processing plants of today are precision instruments and demand a uniform high quality product from their suppliers.

Most steel producers have built up their research and operating facilities to meet this new and advanced set of conditions. It is even true that there are certain refined steels and

Steps in Slag Control: Measuring Slag Temperature and (Right) Taking a Pancake Test

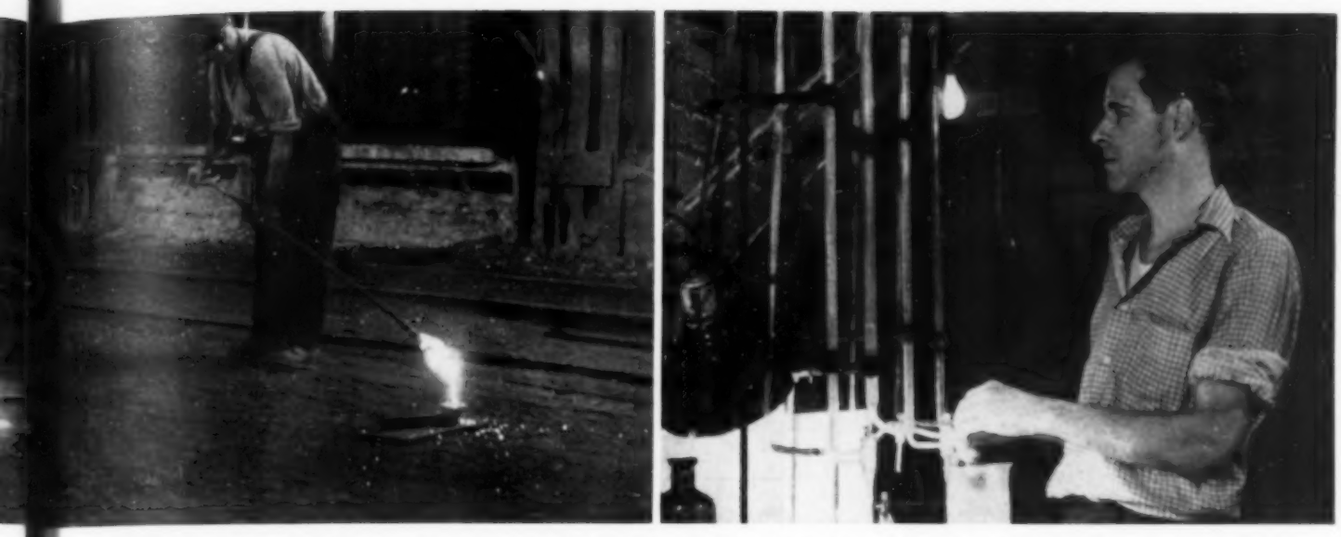
processes which are so new that many consumers have not yet been able to take full advantage of their possibilities. Such a process is the recently developed "austempering," advanced by Bain and Davenport — a method of producing, in effect, a carbon steel with "alloy properties" through a carefully regulated quenching into a medium above 300° F. but below the steel's critical range. With a hardness comparable to that obtained by conventional methods, austempering markedly improves the toughness as illustrated by resistance to impact, shattering and fatigue, and the ductility as revealed by the free bend test.

Quality Control in Carbon Steel

About four years ago, one of our constituent companies introduced a "controlled" plain carbon steel, foreseeing the demands of processing metallurgists for an inexpensive steel of predetermined uniformity. At that time, the stress was placed on grain size control as being particularly applicable to forged, machined, or heat treated parts. It is not necessary here to relate the economies and refinements in tools and parts resulting from the judicious selection of steel with proper grain size. Industry is well acquainted with its value due to its ready control of uniform hardenability, improved impact strength for a given hardness, insurance against forging ruptures and trimmer cracks, less sensitivity to temperature variations and all-around suitability to hot or cold fabrications — truly an imposing list of excellences.

Today, reputable steel makers have taken full advantage of that impetus of four years ago and are giving consumers most valuable assistance in their program of widening the scope of carbon steels. For instance, low carbon strip of definite grain size is making a better and more uniform ball bearing race than ever before, since hardness penetration, distortion and other factors of carburizing operations are under exact control. The possibility of single quenching offers another decided economic advantage. Certain gear manufacturers are taking advantage of steel control by specifying fine grain on one section and coarse grain on another, thus permitting a uniformly hardened product with a single standardized heat treating schedule. An agricultural chain manufacturer is reeling up miles of finished chain made to very restrictive physical properties, with the result as he states, that by ". . . patient endeavors and untiring research the quality (of steel) suitable for our requirements is now at a very high standard and of dependable uniformity . . . the physical properties of our chain have been increased by at least 25%."

Grain size control will continue to be an important factor in the manufacture of a better carbon steel. Of more importance right now is the fact that the impetus furnished by the elaborate mechanism required to control melting practice had a great deal to do with setting in motion many other and newer advancements in carbon steels. It is this continued eagerness of steel technicians to take full advantage of control methods in related fields that has led



Steps in Slag Control: Pouring Test for Slag Viscosity and (Right) Rapid Analysis in Openhearth Laboratory

to much of the recent progress in the manufacture and application of carbon steel.

The term "control" should therefore be understood to have two definite aspects, not only the possibility of making carbon steel of different characteristics at will, but also the ability to hold an individual type to a single standard of performance with great regularity, heat after heat.

In the Carnegie-Illinois Steel Corp. alone, there are approximately 500 young technical graduates working turns in the plants, their sole responsibility being to observe and record for their supervisors all data relating to the steel making and finishing processes. Through this 24-hr. watchfulness and through associated control laboratories, life histories of all the steels are studied, frequency curves of variables established and final recommendations made. The operating personnel are thus enabled to pass upon the customer's problems, not as an isolated individual but as a collaborative force of many trained men.

Today's steel plant is an enormous research laboratory out of which has come an improved carbon steel. Modern steel making is a well ordered, concise program of quality control.

Openhearth slag control has done much to further this new state of the art. Latest tendencies confirm the wisdom of having an intimate knowledge of lime-silica ratios in the slag, so that through compensating additions during later stages in the working of the heat, the desired slag composition is attained for the particular grade of steel being made. The openhearth operator must be able to control not only chemical composition of the slag but its physical characteristics as well. Rapid chemical determinations supplementing visual observation of slag pancake samples regarding temperature, color, texture and viscosity, permit the furnace to be controlled within narrow ranges. Resultant steels are cleaner, more uniform in characteristics, and well adapted to the particular needs of the customer.

Technique of Slag Control

Photographs across the top of these two pages illustrate four of the steps in openhearth slag control, namely:

1. Pouring slag to determine temperature.
2. Pouring slag to observe texture, color and viscosity of the cooled cakes as an indication of lime-silica ratio and other quality factors. Individual pictures of these cakes on following pages also illustrate how surface appearance varies with known differences.
3. Testing slag for viscosity by means of the viscosimeter.
4. Quick chemical determination of slag in openhearth control laboratory.

The slag pancake samples made during the progress of the heat of steel are a most valuable aid to the operator in his control of steel quality. The experienced man is able to read intelligently between the lines and creases of the pancake. The five photographs indicate, for example, an increase of lime-silica ratio of 1.7 to 1 on the first to 4.2 to 1 on the last.

(Continued beyond the next two data sheets)

Method for Identification of Inclusions in Iron and Steel

Originated by Wm. Campbell and G. F. Comstock (Proc. A.S.T.M., Vol. 23, p. 521) and Modified by C. R. Wohrman, Merrill Scheil and Miss M. Baeyertz

Polish Specimen Carefully so as to Preserve Inclusions and Project Magnified Image on Ground Glass by Arc or Equally White Light Without Color Screen

Gray or Black Inclusions

Etch 10 sec. with 10% nitric acid in alcohol

Strongly Attacked — LIME COMPOUND from mold wash (rare)

Unattacked — Etch 5 min. with 10% chromic acid in water (Be careful to observe that the polished surface is wetted by the solution)

Weakly Attacked (slightly pitted or darkened) — COMPOUND OXIDE: (a) either FeO with FeS in solution (usually accompanied by FeO-FeS EUTECTIC), or (b) FeO+MnO and other OXIDES in solution
Note 1: Octahedral crystals are probably MAGNETITE.
Note 2: Both (a) and (b) will be darkened further by 20 sec. sulphur printing (2% H_2SO_4 in water) and destroyed by etching with stannous chloride as indicated below

Attacked — FeS-MnS, rich in MnS. Note: Reaction not always decisive. Any unattacked FeS-MnS will be blackened by next treatment

Completely Blackened — (1*) FeS-MnS, MnS below 50% (2*) FeS-MnS, MnS above 50% or OXIDE very rich in MnO
* Refer to color before etch

Partly Attacked — (a) OXIDE rich in MnO (will be destroyed by stannous chloride) (b) SILICATE with some MnO (will be destroyed by hydrofluoric acid)

Unattacked — (or partly attacked in previous treatments) etch 10 min. with a saturated solution of stannous chloride in alcohol

Attacked — IRON OXIDE or (if previously pitted) COMPOUND OXIDE

Unattacked — (or previously pitted) etch 10 min. with 20% aqueous solution of hydrofluoric acid.

Attacked — SILICATE (if previously pitted presence of Mn is indicated)

Unattacked — Repolish and note color and form

If fine particles, very dark color, difficult to polish without pitting and not elongated by hot work is ALUMINA

If color not especially dark, easily polished smooth without pitting

Fairly large angular fragments, showing changeable bright spots as focus is changed, are SAND GRAINS (in steel castings)

Small angular particles, bluish in color probably TITANIUM OXIDE (in titanium treated steels)

Inclusions of Warm Colors

Etch 10 min. with boiling alkaline sodium picrate

Attacked — IRON SULPHIDE (pale yellowish)

Unattacked — Etch 10 min. in 20% aqueous solution of HF

Attacked: Removes ZIRCONIUM NITRIDE (yellow cubes) and ZIRCONIUM SULPHIDE (tan crystals)

Unattacked Inclusions in high chromium steels — Etch 5 min. in boiling 10% H_2SO_4 + 1% $KMnO_4$, & lightly repolish

Unattacked — CHROMIUM OXIDE (purplish gray by reflected light, bright green by transmitted light)
TITANIUM NITRIDE (yellow cubes)
TITANIUM CYANO-NITRIDE (pinkish; strongly angular, easily pitted in polishing)

Attacked — CHROMITE $Cr_2O_3 \cdot FeO$, isotropic; red to brown by transmitted light

Supplementary Tests

In all instances check determinations in the light of the evidence of a careful chemical analysis, and, whenever possible, by other methods, such as:

I Sulphur Printing

(for 20 sec. using a 2% aqueous solution of H_2SO_4)
(1) Dissolves all FeS-MnS inclusions
(2) Partly dissolves (pits) FeO containing FeS and OXIDES of other metals in solution
(3) Leaves unchanged: IRON SULPHIDE (pale yellow), pure IRON OXIDE (medium grey), SILICATES (dark grey)

II Matweieff's Tests

(a) Dilute tartaric acid does not attack OXIDES or SILICATES, but colors MnS lightly and FeS decidedly
(b) Heat sample in hydrogen at 1600°F., OXIDES are reduced, SILICATES and SULPHIDES are unaffected
(c) Repolish (b), etch with dilute $FeCl_3$ in alcohol, if reduced oxide particles are colored deeply they contain some Mn

III Rohl's Test for Sulphides

Short etch with 1% picric acid in alcohol, then temper to dark yellow. FeS turns dark blue to reddish violet, and MnS turns dull grey to bright white.

Standard Grain Sizes for Steels

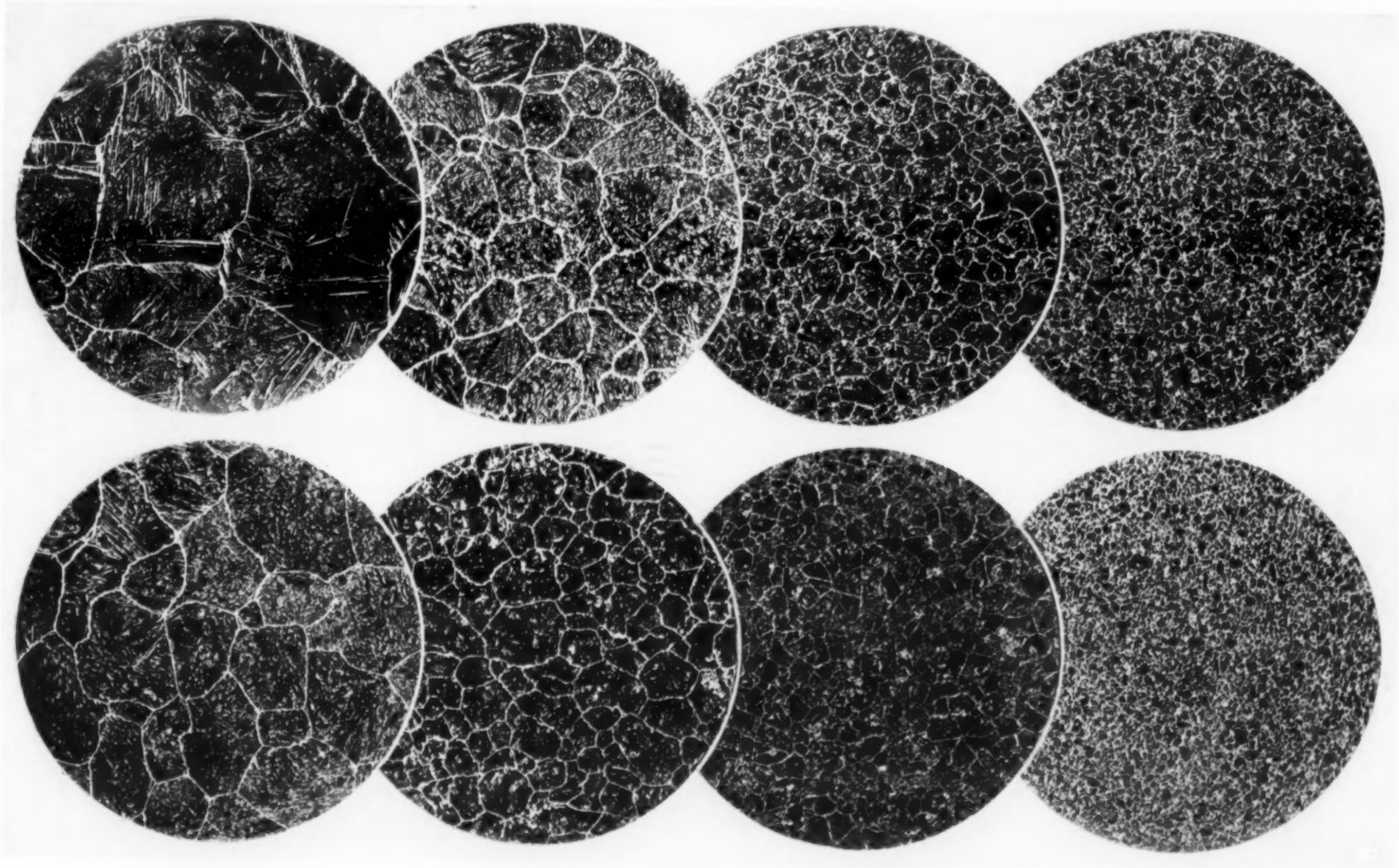
Carburized and slowly cooled to develop cementite network. Magnified 100 diameters. Micros courtesy Timken Roller Bearing Co.

Grain Size No. 1; Up to 1½ per sq.in.

No. 3; 3 to 6 grains per sq.in.

No. 5; 12 to 24 grains per sq.in.

No. 7; 48 to 96 grains per sq.in.



No. 2; 1½ to 3 grains per sq.in.

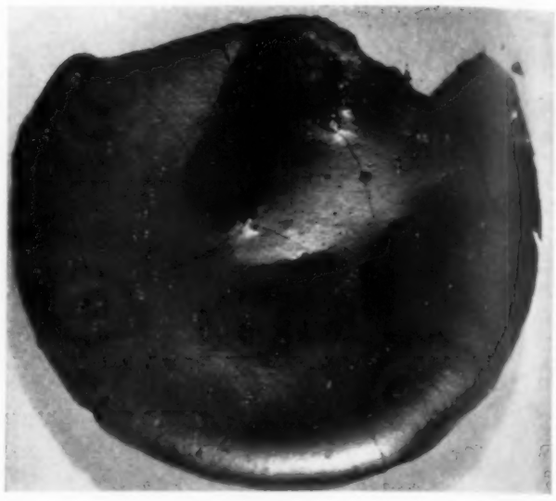
No. 4; 6 to 12 grains per sq.in.

No. 6; 24 to 48 grains per sq.in.

No. 8; More than 96 grains per sq.in.

The nicety of control and complete culmination of plans which surround the tapping and pouring of today's steel would entirely bewilder the steel maker of only ten years ago. Seconds click off on stop-watches, deoxidizers sift in by the ounce, 3 to 20-ton ingots are born with the same care and technique that attends a modern delivery room. Little wonder that today's carbon steel maker takes a personal pride in the part he has played in furnishing his customer with an improved and more uniform product, "custom tailored" to his specific application.

In the past, excessive cold straightening of many critical heat treated parts developed internal strains to the extent that fatigue life was dangerously near the minimum. By careful



Circular Furrow, Rather Shiny; Lime-Silica 2.7 to 1

Slag Pancakes of Increasing Basicity
Lime-Silica Ratio; 1.7 to 1. Furrowed with fine creases

selection of uniform controlled steel, consistent from heat to heat, the heat treater has recently been able to make his plans with definite allowance for a certain small amount of warpage and distortion. He is thus able to reduce cold straightening with a resultant marked improvement in fatigue life. This advantage holds particularly where it is not possible or economical to submit the parts to a sub-critical, stress relieving anneal.

Let us consider low carbon strip, sheet and tinplate which accounts for a large percentage of steel production. The fabricators of these materials will be ready to point out, for example, that difficult parts such as torpedo windshields, front fenders and beer-can tops could never have come so uniformly and economically perfect out of their presses with the steel of only a few years ago. Their technique advanced no more rapidly than the ability of steel makers to meet their requirements.

Open poured or rimmed low carbon steel has long been used for cold rolling and ultimate processing into headlight shells, radio tubes, and similar deep draws. Many operators of presses and equipment for fabricating these parts have recently noticed

1. A more uniform hardness from edge to edge across the full strip or sheet width.
2. Greatly reduced tendency of the steel to draw unevenly or "ear" when deep formed.
3. Decreased tendency for grain coarsening following annealing and cold forming.

Reasons for these improvements go directly back to a novel and completely controlled adaptation of the usual working, deoxidation

Shiny Black, With Spider Web; Lime-Silica 2.7 to 1

and pouring practice common to rimming steel.

Steels for use in automatic screw machines and other turning operations have also been improved to keep pace with the greatly increased spindle speeds and new cutting tools incorporated in high speed machine tools. Bessemer screw stock is no longer the product of a 20-min. blow in a converter with a few shovels of sulphur added! To obtain that uniform distribution of sulphides and that freedom from abrasive inclusions now demanded by the customer has necessitated a new manufacturing technique. Observers and their attendant technical controls have moved in bodily alongside the blower's pulpit. These bessemer steels, with or without sulphur, have been refined to

Slag Pancake Sample With Black Surface Network Covered With Iridescent Film; Lime-Silica 3.7 to 1

permit of forging, heat treating and machining to final physical properties well in line with the finest openhearth grades. Gun barrels, spark plugs and spinning rings (to mention but three) can now be fabricated from controlled bessemer steel to meet precision acceptance tests. The night sky's reflected glow of roaring bessemer flames is symbolic of a continued market for America's oldest steel making process, readjusted to meet today's severe demands through controlled manufacture.

Cold pressed nuts are an example of a common product that presents many problems to the steel maker. Manufacturing a steel to meet a desired combination of ductility and strength, along with punching, burnishing and tapping properties, is a challenge to the state of perfection of steel making practice. Yet within the last few months, production runs on millions of nuts at one plant have shown consistent results actually several times better than ever before experienced. It is hard to believe that four fold tool life, doubled output and better looking product can result from a steel metallurgist's conception of a new and novel attack on an old steel production problem, but it is demonstrated in innumerable American plants.

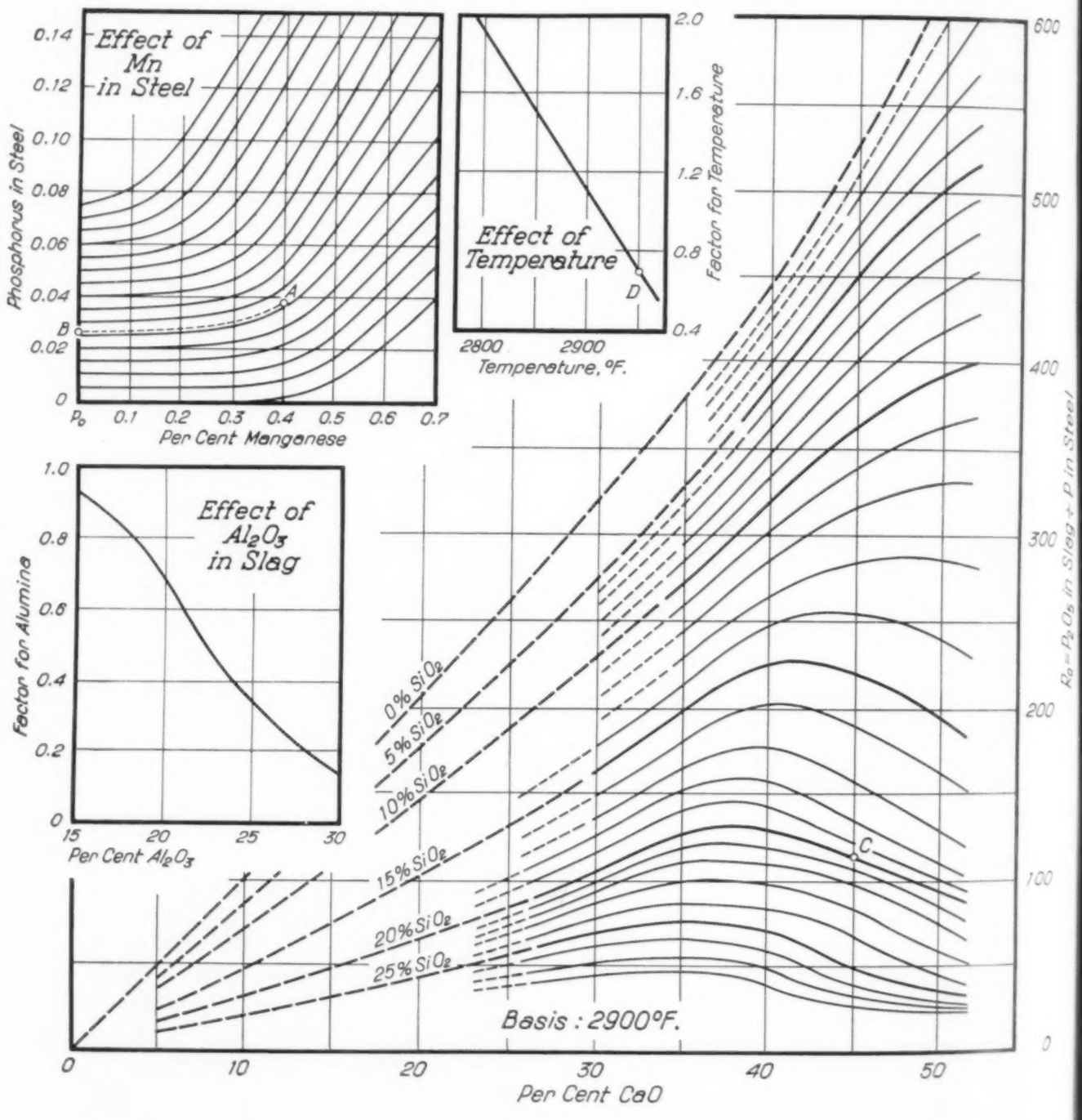
Every day carbon steels are taking new assignments where utmost care must be exercised to employ only steel of extreme freedom from inclusions. Internal defects are being forced out into the open by new standards of inspection. Axles, shafts, rotors, and many similar parts are purchased for unheard of service requirements. Only by careful selection of raw materials, control of furnace slags which govern oxidation, and control of every step in the pouring practice can the steel maker obtain the necessary freedom from internal seams.

Much depends on the absolute control of roughing and finishing temperatures of hot rolled products. Slabs thundering out of reheating furnaces are automatically heated to a temperature which will result in a finished product issuing from the last rolling pass within a narrow range of temperature. The photo-electric cell stationed directly over the moving steel assists the operators in guaranteeing that the precise combination of necessary ductility and strength is found in the fabricator's sheet when tested sometime later. *(Cont. on page 444)*

Spangled Slag Pancake Sample; Lime-Silica 4.2 to 1

Phosphorus Balance, Basic Steel to Slag

According to E. Maurer and W. Bischof



EXAMPLE: If a slag contains 45% CaO and 20% SiO_2, locate *C* and read 114 at the right, the value of R_o, which is the ratio between P_2O_5 in the slag and P in a manganese-free steel. If the slag analyzes say 3.00% P_2O_5, there will be 3.00 ÷ 114 = 0.026% in the manganese-free steel. For the actual steel, analyzing say 0.40% Mn, find 0.026 (point *B* in the upper left diagram) and carry across by guide curves to *A* above 0.40% Mn. Soft and medium steel in equilibrium with the above slag in a basic furnace will therefore have about 0.038% P.

The above assumes normal temperature (2900° F.) and low alumina slags. Corrections for temperature and alumina should be made by multiplying R_o by the indicated ratio from the two small diagrams before following the other steps noted above.

Booth E – 32

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Carbon Steel

(Starts on page 431)

Through recent refinements in control of manufacture and processing, carbon steel rails and wheels are able to meet the increased speeds and loads of modern rail transportation. Economies are effected through special heat treatments which minimize rail-end batter and increase the wearing qualities of wheel treads.

What could be more precise than the absolute control in making a 100-ton heat of high carbon rock-drill bit steel, so that each one-inch round bar rolled from 14 miles of steel will uniformly possess a certain specified fineness of fracture and a definite depth of hardness penetration when heated and quenched? Rock-drilling bits are precision tools and must be made from a precisely controlled steel.

For certain applications carbon steels as well as some alloy steels are being successfully surface-hardened by induction heating and differential quenching. This method, which was described by Tran and Benninghoff before the [illegible] Convention in Cleveland last year, is an excellent example of a controlled process where the important factors are automatically reproduced to insure complete uniformity. The same precision methods must be applied to the manufacture of steel to be hardened in this interesting manner.

Carbon Vs. Alloy Steels

Naturally, there will always be a distinction between alloy and plain carbon steels. New and better alloys will be developed and always there will be economical uses for the best that the steel maker can offer. However, there is no escape from the simple truth that a balance between cost and service required will always be found. If higher and more expensive alloys are finding new uses, it is only because they are economically cheap. If lower alloys are satisfactorily replacing higher alloys in certain applications, it is only because progress can not be impeded. Finally, if carbon steels are to find new favor, it will come about only through definite progress in the control of steel quality by the producer and in methods of processing by the consumer.

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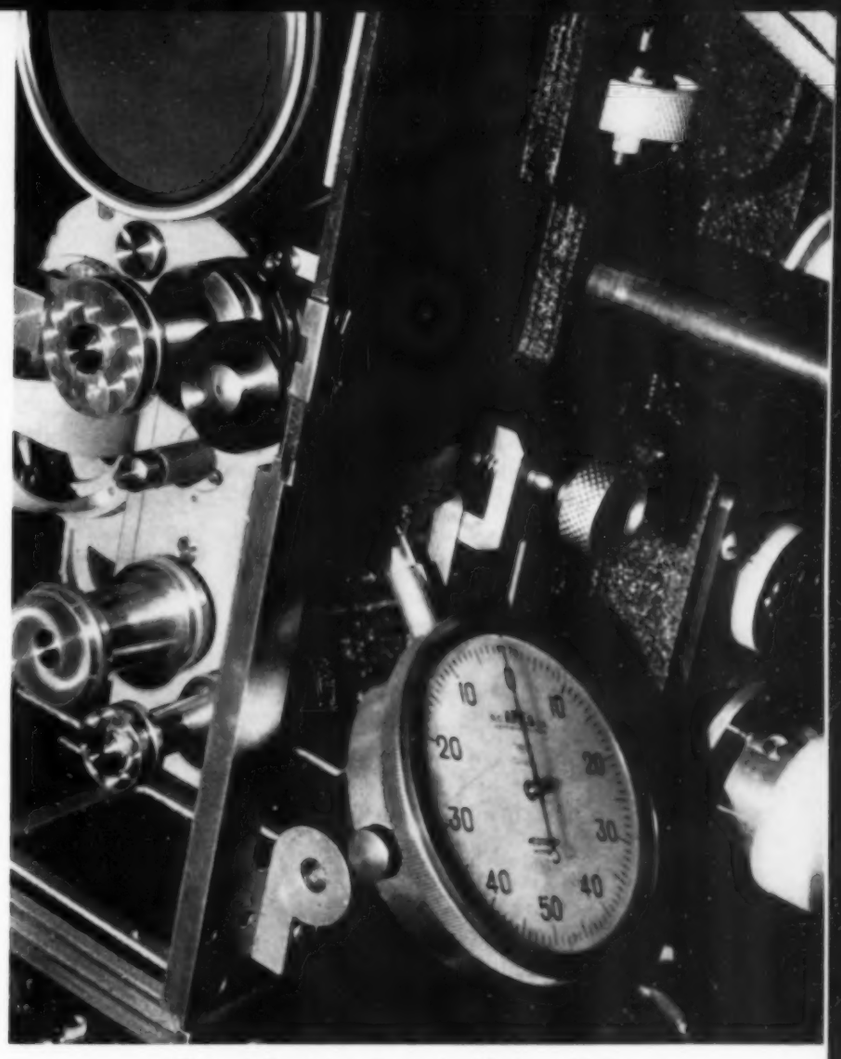
Trends in Alloy Steels in England

By J. H. G. Monypenny
Metallurgist
Brown, Bayley's Steel Works
Sheffield, England



Test of Precision Gears in Motion (Movie-Sound Camera). Photo by Irving Browning

A WIDESPREAD use of alloy steels justifies the description "The Alloy Steel Age" as applying to present times but makes it practically impossible to summarize, in an article of reasonable length, the many trends and improvements which may be observed in the very varied uses of these steels. Consideration can be given only to some particular phase of their use. The principal reason why alloy steels are employed in engineering work is because they give better combinations of mechanical properties than can be obtained from ordinary carbon steels; and from this point of view their application could be divided broadly into three categories:

1. Constructional steels that are not generally heat treated — or, if they are, only in a simple fashion, for example by normalizing. The addition of certain alloys, as chromium or copper to these steels, or the increase beyond the ordinary content of silicon or manganese, produces an increase in tensile strength which, though small, may be quite significant.

2. Bars and forgings up to perhaps 5 or 6 in. in diameter, but often 2 in. or less, which are heat treated to possess high tensile strength combined with good toughness so as to meet the demands, which become yearly more exacting, of the aircraft and automobile industries. These bars and forgings are also being used to an increasing extent for general engineering.

3. Very large forgings — such as shafts for turbo-alternators, drums for high pressure steam boilers and for chemical processes — in the forging and heat treatment of which special problems arise.

Although the primary urge — the attainment of better mechanical properties — is probably the same in all three cases, the methods of obtaining the improved qualities differ considerably. To deal adequately with all three would require too long an article; it is intended therefore to consider only the second class, namely the bars and forgings of relatively small size, and to point out the general trends in the compositions of the steels so used and in the ranges of mechanical properties which are being obtained.

Casehardening Steels

For casehardening steels, nickel is still the alloy par excellence; no other alloy has yet been found which will produce, by itself, such a good combination of strength and toughness in the core of a hardened carburized article as does nickel. It may be urged of course that core properties are only one side of the picture, and that the production of a hard, uniform case is at least as important. This is agreed and where core properties are presumably of less importance, use has been made of casehardening steels containing 1% or so of chromium. With a proper adjustment of composition, such steels will give file-hard cases after quenching in oil, if the size is not too great. The core strength of these steels, however, is not very high — possibly 90,000 to 100,000 psi. — and their toughness, as measured by the Izod impact test, is rather low. A steel with the chromium replaced with an equal amount of nickel would require quenching in water to harden it effectively (unless the section were very small) but would then give as good core strength as the chromium steel and much greater toughness.

Frequently, however, higher tensile strength is required in the core, for example to give adequate support to the carburized skin against heavy pressure or because the complete part is intended to transmit power and is highly stressed. In the latter instance, particularly, high strength should be combined with adequate toughness, and nickel (either singly or with chromium or molybdenum or both) supplies these demands. Steels containing 3% and 5% nickel are frequently used, the former to give a tensile strength of 100,000 to 135,000 psi. (British Standards Institution specification 3.S.15) and the latter to give a minimum of 145,000 psi. (B.S.I. specification S.90). The minimum Izod impact values required by these specifications are respectively 40 and 30 ft-lb., but much higher figures can be obtained, particularly from carefully made, electrically melted steels. For example, Izod impact values of 100 ft-lb. and over with tensile strengths of approximately 110,000 psi., and of 80 ft-lb. with 130,000 psi., have been given by the 3% nickel steels, while results from those of the 5% class have included values of 45 to 50 ft-lb. with 170,000 psi., and 40 ft-lb. with 180,000 psi. tensile strength. Occasionally small additions of molybdenum are made to these steels, particularly those with the higher nickel content, and these undoubtedly help in obtaining the desired combination of high strength and toughness.

When a still higher tensile strength than those mentioned above is required, nickel-chrome or nickel-chrome-molybdenum steels are generally used and these are capable of giving 190,000 to 210,000 psi. with really good toughness values. B.S.I. specification S.82 covers these steels and calls for the following minimum properties:

Tensile strength	190,000 psi.
Elongation	12%
Reduction of area	35%
Izod impact	25 ft-lb.

These requirements are severe but they can be met with carefully made acid openhearth steel. Impact values much in excess of the specified minimum can, however, be got from electrically melted steel as indicated below, the second result showing that this is true even if the tensile value is considerably higher than the minimum specified:

Core Tests on Casehardened Nickel-Chrome-Molybdenum Steels (Electrically Melted)

Tensile Strength	Izod Impact
191,000 psi.	58 ft-lb.
211,000 psi.	43 ft-lb.

The nickel-chrome casehardening steels have also the advantage that they give a harder case than that of a 5% nickel steel. For this reason, nickel-chrome steels, with or without molybdenum, of a somewhat lower alloy content than is necessary to meet specification S.82 are often used in Great Britian, instead of the 5% nickel steels, to give core strengths of 150,000 psi. or thereabouts.

Test Pieces

It may perhaps be useful to call attention here to the general practice in England of using a standard size bar — namely 1⅛ in. diameter — in testing casehardening steels. All these steels show mass effects, some in a very marked manner. Hence, in order to facilitate comparisons between different steels and to enable reasonable specifications to be drawn up, tests are always made on bars of the standard diameter whenever this is possible. If tests have of necessity to be made on small pieces appropriate allowances may be made.

Likewise it should be mentioned that all the Izod impact tests referred to in this article were obtained with the British standard form of test piece which is 10 mm. square and notched

Analyses of S.A.E. Steels

Numerical designations and analyses approved as standard by Society of Automotive Engineers

Carbon Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulphur Max.
1010	0.05-0.15	0.30-0.60	0.045	0.055
1015	0.10-0.20	0.30-0.60	0.045	0.055
X1015	0.10-0.20	0.70-1.00	0.045	0.055
1020	0.15-0.25	0.30-0.60	0.045	0.055
X1020	0.15-0.25	0.70-1.00	0.045	0.055
1025	0.20-0.30	0.30-0.60	0.045	0.055
X1025	0.20-0.30	0.70-1.00	0.045	0.055
1030	0.25-0.35	0.60-0.90	0.045	0.055
1035	0.30-0.40	0.60-0.90	0.045	0.055
1040	0.35-0.45	0.60-0.90	0.045	0.055
X1040	0.35-0.45	0.40-0.70	0.045	0.055
1045	0.40-0.50	0.60-0.90	0.045	0.055
X1045	0.40-0.50	0.40-0.70	0.045	0.055
1050	0.45-0.55	0.60-0.90	0.045	0.055
X1050	0.45-0.55	0.40-0.70	0.045	0.055
1055	0.50-0.60	0.60-0.90	0.040	0.055
X1055	0.50-0.60	0.90-1.20	0.040	0.055
1060	0.55-0.70	0.60-0.90	0.040	0.055
1065	0.60-0.75	0.60-0.90	0.040	0.055
X1065	0.60-0.75	0.90-1.20	0.040	0.055
1070	0.65-0.80	0.60-0.90	0.040	0.055
1075	0.70-0.85	0.60-0.90	0.040	0.055
1080	0.75-0.90	0.60-0.90	0.040	0.055
1085	0.80-0.95	0.60-0.90	0.040	0.055
1090	0.85-1.00	0.60-0.90	0.040	0.055
1095	0.90-1.05	0.25-0.50	0.040	0.055

Free Cutting Steels

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Range	Sulphur Range
1112	0.08-0.16	0.60-0.90	0.09-0.13	0.10 -0.20
X1112	0.08-0.16	0.60-0.90	0.09-0.13	0.20 -0.30
1115	0.10-0.20	0.70-1.00	0.045 max.	0.075-0.15
1120	0.15-0.25	0.60-0.90	0.045 max.	0.075-0.15
X1314	0.10-0.20	1.00-1.30	0.045 max.	0.075-0.15
X1315	0.10-0.20	1.30-1.60	0.045 max.	0.075-0.15
X1330	0.25-0.35	1.35-1.65	0.045 max.	0.075-0.15
X1335	0.30-0.40	1.35-1.65	0.045 max.	0.075-0.15
X1340	0.35-0.45	1.35-1.65	0.045 max.	0.075-0.15

Manganese Steels

See Note (a) for Silicon Content

No.	Carbon	Manganese	Phosphorus	Sulphur
T1330	0.25-0.35	1.60-1.90	0.040 max.	0.050 max.
T1335	0.30-0.40	1.60-1.90	0.040 max.	0.050 max.
T1340	0.35-0.45	1.60-1.90	0.040 max.	0.050 max.
T1345	0.40-0.50	1.60-1.90	0.040 max.	0.050 max.
T1350	0.45-0.55	1.60-1.90	0.040 max.	0.050 max.

Nickel Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur Content

No.	Carbon	Manganese	Nickel
2015	0.10-0.20	0.30-0.60	0.40-0.60
2115	0.10-0.20	0.30-0.60	1.25-1.75
2315	0.10-0.20	0.30-0.60	3.25-3.75
2320	0.15-0.25	0.30-0.60	3.25-3.75
2330	0.25-0.35	0.50-0.80	3.25-3.75
2335	0.30-0.40	0.50-0.80	3.25-3.75
2340	0.35-0.45	0.60-0.90	3.25-3.75
2345	0.40-0.50	0.60-0.90	3.25-3.75
2350	0.45-0.55	0.60-0.90	3.25-3.75
2515	0.10-0.20	0.30-0.60	4.75-5.25

Molybdenum Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur Content

S.A.E. No.	Carbon	Manganese	Chromium	Nickel	Molybdenum
4130	0.25-0.35	0.50-0.80	0.50-0.80	.....	0.15-0.25
X4130	0.25-0.35	0.40-0.60	0.80-1.10	.....	0.15-0.25
4135	0.30-0.40	0.60-0.90	0.80-1.10	.....	0.15-0.25
4140	0.35-0.45	0.60-0.90	0.80-1.10	.....	0.15-0.25
4150	0.45-0.55	0.60-0.90	0.80-1.10	.....	0.15-0.25
4340	0.35-0.45	0.50-0.80	0.50-0.80	1.50-2.00	0.30-0.40
4345	0.40-0.50	0.50-0.80	0.60-0.90	1.50-2.00	0.15-0.25
4615	0.10-0.20	0.40-0.70	.....	1.65-2.00	0.20-0.30
4620	0.15-0.25	0.40-0.70	.....	1.65-2.00	0.20-0.30
4640	0.35-0.45	0.50-0.80	.....	1.65-2.00	0.20-0.30
4815	0.10-0.20	0.40-0.60	.....	3.25-3.75	0.20-0.30
4820	0.15-0.25	0.40-0.60	.....	3.25-3.75	0.20-0.30

Chromium Steels

See Note (a) for Silicon Content

S.A.E. No.	Carbon Range	Manganese Range	Phosphorus Max.	Sulphur Max.	Chromium Range
5120	0.15-0.25	0.30-0.60	0.040	0.050	0.60-0.90
5140	0.35-0.45	0.60-0.90	0.040	0.050	0.80-1.10
5150	0.45-0.55	0.60-0.90	0.040	0.050	0.80-1.10
52100	0.95-1.10	0.20-0.50	0.030	0.035	1.20-1.50

Nickel-Chromium Steels

See Notes (a) and (b) for Silicon, Phosphorus and Sulphur Content

No.	Carbon	Manganese	Nickel	Chromium
3115	0.10-0.20	0.30-0.60	1.00-1.50	0.45-0.75
3120	0.15-0.25	0.30-0.60	1.00-1.50	0.45-0.75
3125	0.20-0.30	0.50-0.80	1.00-1.50	0.45-0.75
3130	0.25-0.35	0.50-0.80	1.00-1.50	0.45-0.75
3135	0.30-0.40	0.50-0.80	1.00-1.50	0.45-0.75
3140	0.35-0.45	0.60-0.90	1.00-1.50	0.45-0.75
X3140	0.35-0.45	0.60-0.90	1.00-1.50	0.60-0.90
3145	0.40-0.50	0.60-0.90	1.00-1.50	0.45-0.75
3150	0.45-0.55	0.60-0.90	1.00-1.50	0.45-0.75
3215	0.10-0.20	0.30-0.60	1.50-2.00	0.90-1.25
3220	0.15-0.25	0.30-0.60	1.50-2.00	0.90-1.25
3230	0.25-0.35	0.30-0.60	1.50-2.00	0.90-1.25
3240	0.35-0.45	0.30-0.60	1.50-2.00	0.90-1.25
3245	0.40-0.50	0.30-0.60	1.50-2.00	0.90-1.25
3250	0.45-0.55	0.30-0.60	1.50-2.00	0.90-1.25
3312	max. 0.17	0.30-0.60	3.25-3.75	1.25-1.75
3325	0.20-0.30	0.30-0.60	3.25-3.75	1.25-1.75
3335	0.30-0.40	0.30-0.60	3.25-3.75	1.25-1.75
3340	0.35-0.45	0.30-0.60	3.25-3.75	1.25-1.75
3415	0.10-0.20	0.30-0.60	2.75-3.25	0.60-0.95
3435	0.30-0.40	0.30-0.60	2.75-3.25	0.60-0.95
3450	0.45-0.55	0.30-0.60	2.75-3.25	0.60-0.95

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Caution: Check with S.A.E. for possible modifications before making important commitments

Chromium-Vanadium Steels

See Notes (a) and (c) for Silicon, Phosphorus and Sulphur

S.A.E. No.	Carbon Range	Manganese Range	Chromium Range	Vanadium Minimum	Vanadium Desired
6115	0.10-0.20	0.30-0.60	0.80-1.10	0.15	0.18
6120	0.15-0.25	0.30-0.60	0.80-1.10	0.15	0.18
6125	0.20-0.30	0.60-0.90	0.80-1.10	0.15	0.18
6130	0.25-0.35	0.60-0.90	0.80-1.10	0.15	0.18
6135	0.30-0.40	0.60-0.90	0.80-1.10	0.15	0.18
6140	0.35-0.45	0.60-0.90	0.80-1.10	0.15	0.18
6145	0.40-0.50	0.60-0.90	0.80-1.10	0.15	0.18
6150	0.45-0.55	0.60-0.90	0.80-1.10	0.15	0.18
6195(c)	0.90-1.05	0.20-0.45	0.80-1.10	0.15	0.18

Tungsten Steels

See Notes (a) and (d) for Silicon, Phosphorus and Sulphur

No.	Carbon	Manganese	Chromium	Tungsten
71360	0.50-0.70	0.30 max.	3.00-4.00	12.00-15.00
71660	0.50-0.70	0.30 max.	3.00-4.00	15.00-18.00
7260	0.50-0.70	0.30 max.	0.50-1.00	1.50- 2.00

Silicon-Manganese Steels

See Note (b) for Phosphorus and Sulphur

No.	Carbon	Manganese	Silicon
9255	0.50-0.60	0.60-0.90	1.80-2.20
9260	0.55-0.65	0.60-0.90	1.80-2.20

Corrosion and Heat Resisting Alloys

See Note (e) for Silicon, Phosphorus and Sulphur Content

No.	Carbon	Manganese	Chromium	Nickel
30905	0.08 max.	0.20-0.70	17.00-20.00	8.00-10.00
30915	0.09-0.20	0.20-0.70	17.00-20.00	8.00-10.00
51210	0.12 max.	0.60 max.	11.50-13.00	.....
X51410	0.12 max.	0.60 max.	13.00-15.00	.....
51335	0.25-0.40	0.60 max.	12.00-14.00	.....
51510	0.12 max.	0.60 max.	14.00-16.00	.....
51710	0.12 max.	0.60 max.	16.00-18.00	.....

Notes to Tables of Chemical Composition

Note (a). Silicon range of all S.A.E. basic openhearth alloy steels shall be 0.15 to 0.30%. For electric furnace alloy steels and acid openhearth alloy steels, the silicon content shall be 0.15% minimum.

Note (b). Phosphorus and sulphur in all S.A.E. nickel steels, nickel-chromium steels, molybdenum steels and silicon-manganese steels shall be 0.040% max. and 0.050% max. respectively.

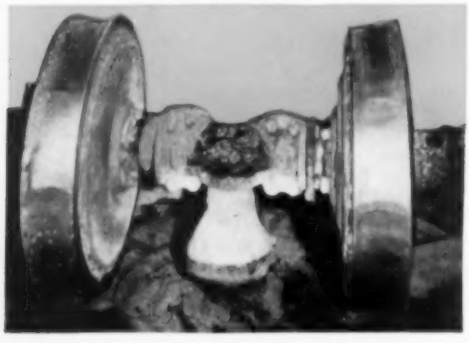
Note (c). Phosphorus in all S.A.E. chromium-vanadium steels shall be 0.040% max. except in No. 6195, which shall be 0.030% max. Sulphur in all S.A.E. chromium-vanadium steels shall be 0.050% max. except in No. 6195, which shall be 0.035% max.

Note (d). Phosphorus and sulphur in all S.A.E. tungsten steels shall be 0.035% and 0.040% max. respectively.

Note (e). Silicon shall be 0.50% max. except in alloys 30905 and 30915, which may be 0.75% max. Phosphorus shall be 0.030% max. in all corrosion and heat resisting alloys. Sulphur shall be 0.030% max. in all except in the free cutting alloy X51410, which shall be in the range 0.15 to 0.50%.

A little NICKEL *makes a* BIG REDUCTION . . .

ENGINE troubles are colossal cost boosters. Failures of vital parts not only involve expensive labor and materials, but they interrupt the entire production cycle. But when engines are equipped with cast irons properly alloyed with a small percentage of Nickel, the danger of breakage and wear is materially reduced. The big fellow at the right turns the screws of the Erie Railroad's new ferryboat, "Meadville", and is equipped with cylinder heads with integrally cast valve seats, cylinders and pistons—all made of enduring Nickel Cast Iron. Two engines of similar design and similarly equipped with Nickel Cast Irons are being used by the Virginia Ferry Corporation and have already run up a total of 336,272 miles with only two minor bearing adjustments and with *no engine repairs of any kind*. These engines are the product of the Skinner Engine Co., of Erie, Pa.



ALMOST diamond hard is the gravel used in the manufacture of silica brick, product of the ceramic industry. Hence in crushing this material to the proper degree of fineness the "Mullers" (see picture above) are subjected to punishing abrasion. Before trying Nickel Cast Iron for these "Muller" tires, one producer averaged around 370,000 brick per tire before replacement. He also tried a mildly alloyed iron tire and did considerably better—50%. Finally he tried Ni-Hard*, a special Nickel Cast Iron composition of unusual hardness, beating the original material by 200% greater production. Incidentally the Ni-Hard tire occupied the "lead" position throughout its service where it received 50% greater wear than the mildly alloyed cast iron tire occupying the hind position. The Ni-Hard tires were made by Simpson Bros. Co., Portsmouth, Ohio, under their trade name "Paulite."

. . . *in costly repairs and replacements*

HERE'S a drum that will take a terrific lot of beating from corrosion because it is made of Ni-Resist*, a Nickel Cast Iron containing usually 14% Nickel, 6% copper and 2% chromium. Specifically, it is a filter drum used in the processing of salt. While its performance record is not yet available its probable life can be fairly accurately estimated by comparing it with that of Ni-Resist filter grids used in the same service.

These grids have been known to deliver 5 years of service as against 4 months for unalloyed plain cast iron. We invite consultation on the use of Nickel Cast Iron and other alloys of Nickel in your equipment.

*Reg. U. S. Pat. Off.
by The International Nickel Company, Inc.
Canadian Patent No. 281,986 and 278,180

NICKEL CAST IRONS

THE INTERNATIONAL NICKEL COMPANY, INC., NEW YORK, N. Y.

with a Vee notch (45° angle) 2 mm. deep, the radius at the bottom being 0.25 mm. A test notched in this way is far more searching than one with a well rounded notch, 1-mm. radius, which is frequently used with Charpy machines. The point is rather important because the latter type of notch, which is practically never used in England, gives distinctly higher values than the former under otherwise similar conditions.

Trend Toward Lower Alloys

In the case of medium carbon steels which are hardened and tempered, nickel occupies a much less prominent position, a greater variety of alloy content being available to give desired properties. Two distinct tendencies may be noted in this field:

1. Obtaining moderately high tensile values by means of relatively cheap steels; this applies particularly to the smaller sizes of bars and forgings used in the automobile industry and in general engineering work.

2. Obtaining improved properties both in small sized bars and forgings, and in those of larger diameter (for instance 3 in. or more), such as might be used for highly stressed parts of aero engines where strength and toughness demand first consideration and initial cost of the steel is of less moment.

Neither of these tendencies is new, of course; they have been observable in greater or less degree for some years, and the first has been particularly in evidence in America, if reports are true. As far as English trends are concerned, some of the results may be reported, as well as the developments which have led up to them.

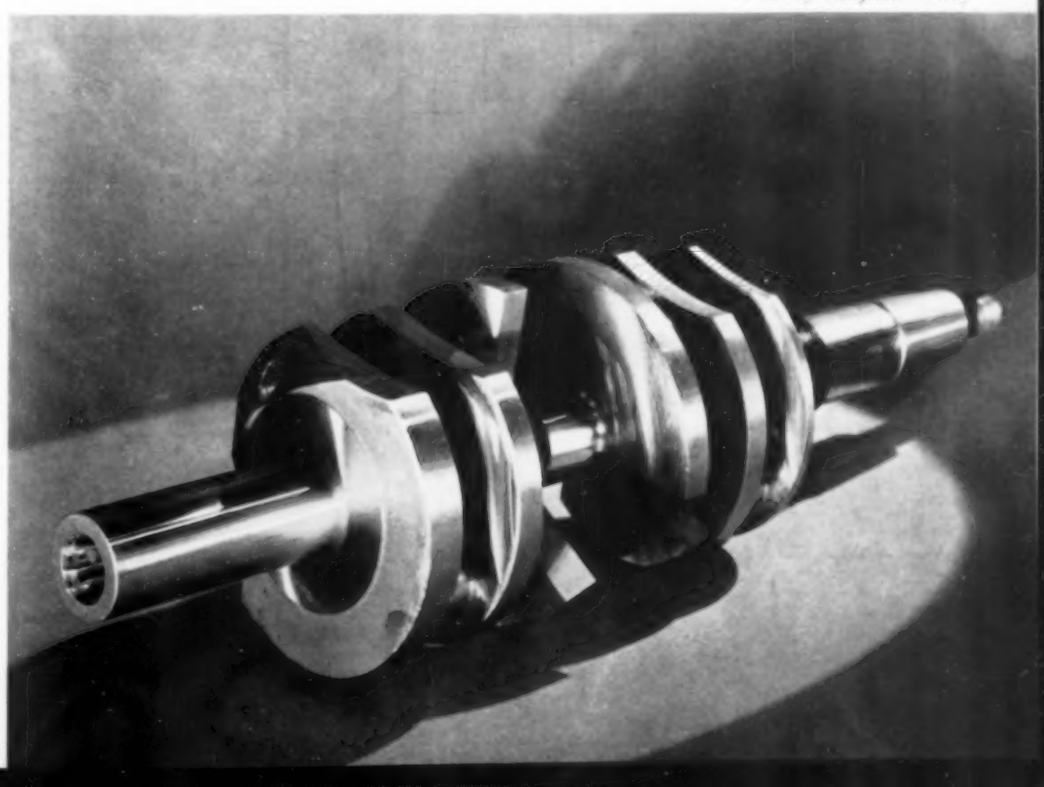
Manganese Steel—Nickel and nickel-chrome steels have been for many years the stand-by of the engineer who wanted better properties than could be obtained from carbon steels, but the high cost of the alloy has led steelmakers to look for cheaper substitutes. One of the earliest was manganese which was added to the extent of about 1½%. This steel was originally used as a water hardening steel and could be effectively hardened in bars 3 or 4 in. in diameter, but the liability for cracking to occur when quenching in water has led most users to substitute oil for the quenching medium with this material.

Under these stated conditions the manganese steel is particularly useful in small sizes—for instance up to 1 in. or 1¼ in. diameter—and will give a tensile strength of 100,000 to 125,000 psi. together with a minimum Izod impact value of 50 ft-lb. A definite improvement was obtained by adding about 0.25% molybdenum; bars up to about 1½ in. diameter would then give with ease a tensile strength of 110,000 to 135,000 psi. with a minimum Izod impact of 50 ft-lb. Larger sizes, up to about 3 in. diameter, would give the same Izod value with a tensile strength of 100,000 to 125,000 psi.; above about 3 in. in diameter, the tensile strength fell off still more but even up to about 5 in., values of 90,000 to 110,000 psi. together with a minimum Izod figure of 40 ft-lb. can be obtained from carefully made steels.

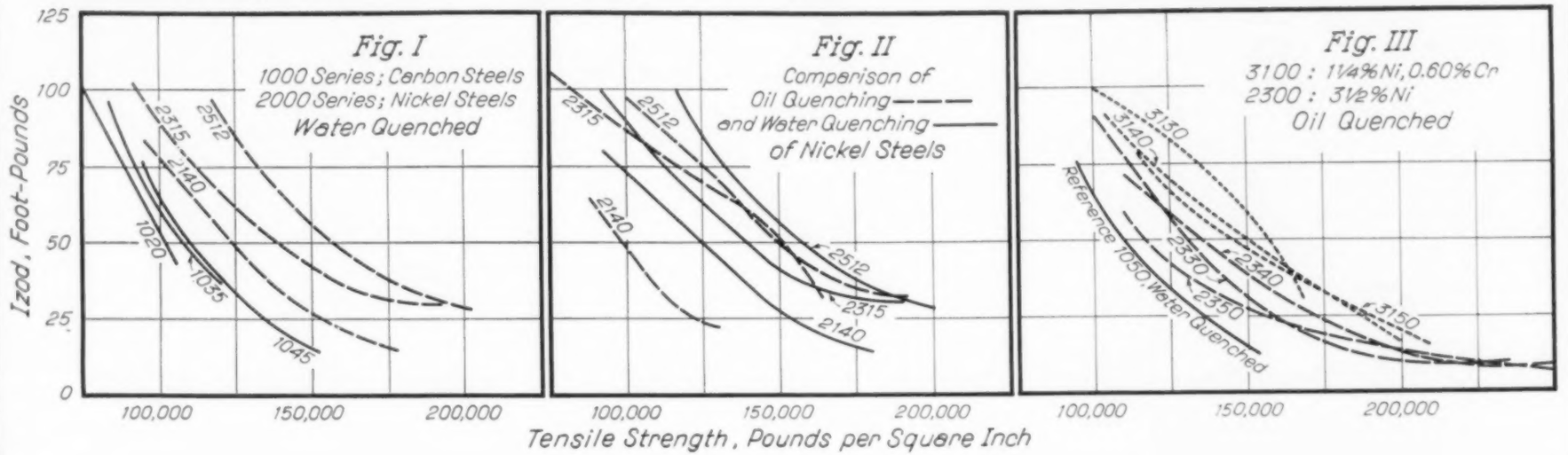
Increasing the molybdenum content to about 0.50% gives still better results; such a steel satisfies the requirements of B.S.I. specification 2.S.2 which calls for 125,000 to 145,000 psi. together with a minimum Izod value of 40 ft-lb. in sizes up to 2½ in. diameter.

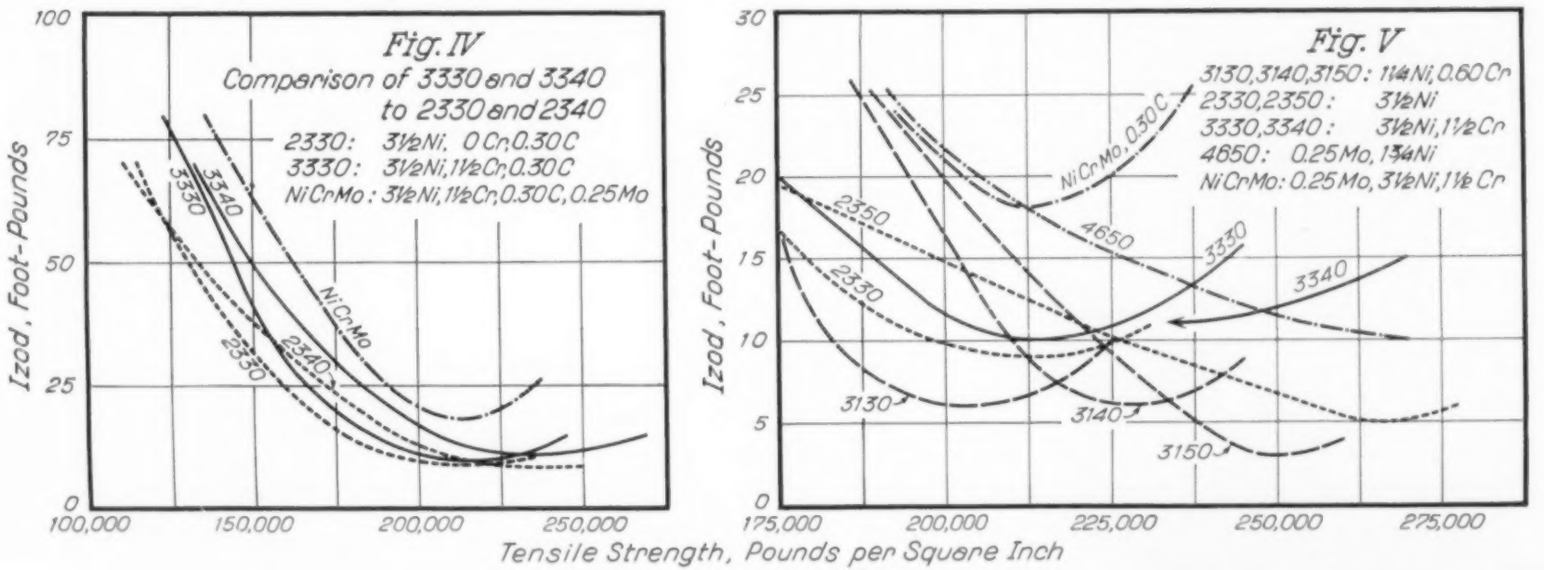
Other variations in the composition of the steel have included additions of small amounts—generally under 0.50%—of chromium or nickel. In the latter case, the addition possibly occurred by chance owing to the inclusion of some scrap containing nickel in the charge. In most cases the aim has been to obtain, at a low cost, tensile strengths of 110,000 to 135,000 or 125,000 to 145,000 psi. with a minimum Izod

Photo by Kaufmann-Fabry



Izod Toughness Vs. Tensile Strength of Heat Treated S.A.E. Steels

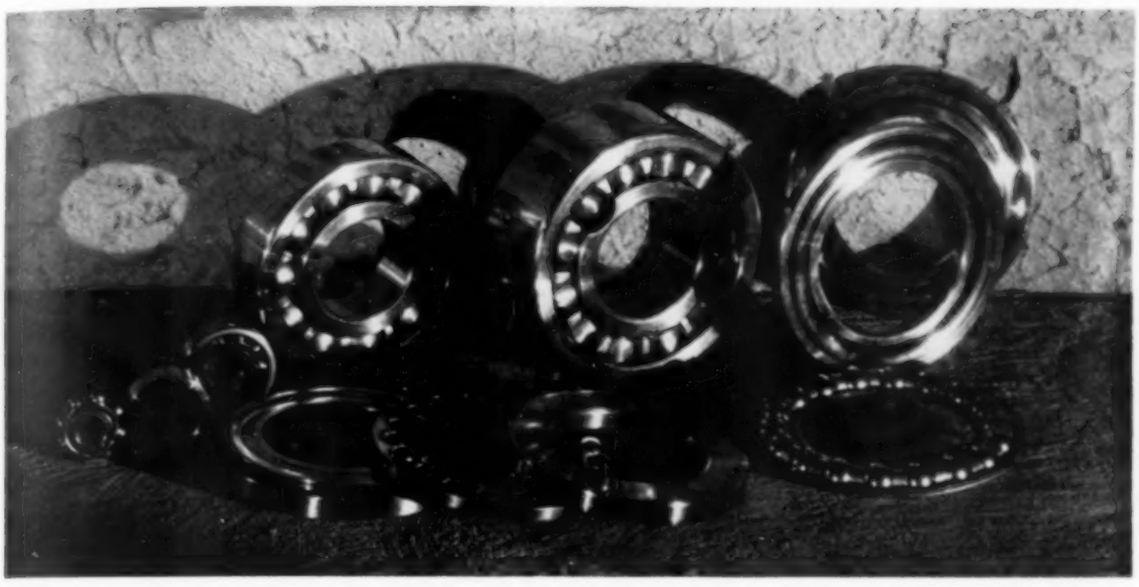




Alloys may be appraised by comparing ratios of toughness to ultimate strength. The above charts do this for some of the S.A.E. steels; the data have been replotted from the handbook on "Nickel Alloy Steels" published

Figures I and II indicate that 0.20 to 0.45% carbon steels are about equal in Izod impact when heat treated to equal strength. Nickel increases the toughness-to-strength ratio materially, especially at high strengths. Figure III shows how a little

about the highest toughness-to-strength ratios available (Fig. IV showing that 1.5% Cr adds 13,500 psi. to the tensile for equal Izod figures throughout the range 15 to 70 ft-lb.). Nickel-chromium-molybdenum steels are remarkable, as can be seen in



Courtesy Fafnir Bearing Co.

impact value of perhaps 40 ft-lb. in material up to 2 or 2½ in. diameter.

Chromium has also formed the base of a series of useful low alloy steels. Steels containing 1.0 to 1.5% of this metal, frequently with the addition also of about 0.20% vanadium, have been used for many years, particularly for high class automobile springs and possibly to a less extent in England as high tensile steels. The plain chromium steel gives good results in small sizes (up to 1¼ in. or so), tensile strengths of 110,000 to 135,000 psi. with a minimum Izod value of 40 ft-lb. being readily obtainable after oil hardening followed by tempering at about 1150° F. Lower tempering temperatures give higher tensile strengths (for instance, 160,000 psi. or more) but there is a marked tendency for the impact value to fall when the steel is tempered below about 1100° F.

Addition of about 0.20% vanadium improves the properties of the plain chromium steels. Good results may also be obtained with molybdenum; by using about 0.30% molybdenum together with 1.0 to 1.5% chromium, one can obtain a steel which will give, in oil hardened and tempered bars up to 2 in. or 2½ in. diameter, 135,000 to 155,000 psi. together with a minimum Izod impact value of 40 ft-lb., which is a very useful combination of properties indeed.

Nickel-Chrome Steels — It will be noted that no mention has been made of the low nickel-chrome steel — containing perhaps 1.5% nickel and 0.8 or 1.0% chromium — which was frequently used eight or ten years ago. Actually the steels described in the last few paragraphs have largely displaced this once popular material in England. The latter admittedly gave good mechanical properties but it was prone to develop surface defects and, in addition, it suffered from temper brittleness which required quenching from tempering heats if good toughness was to be obtained. The newer chrome-molybdenum and manganese-molybdenum steels are free from this disadvantage; they give perfectly satisfactory impact results when air cooled after tempering. The nickel-chrome steel, however, is still used for the production of oil hardened gears; after being hardened and then tempered at 400° F. it gives tensile strengths of the order of 220,000 to 270,000 psi. together with impact values up to 10 or 15 ft-lb.

Where the most exacting demands have to be met — and particularly in the larger sizes — nickel-chrome steels containing roughly 3.5% nickel up to 1.5% chromium (often with a small addition of molybdenum) still occupy pride of place. It may be interesting to note, however, the improvement in properties, particularly in toughness, which has been made possible by a better understanding of steel making conditions.

The ordinary British specification (B.S.I. 3.S.11) for nickel-chrome steel (roughly 3½% nickel, 1% chromium) calls for 125,000 to 145,000 psi. together with a minimum Izod value of 40 ft-lb. Electrically melted steels having this range of tensile strength but with more than

twice the specified Izod value have been regularly produced. Higher tensile strengths are frequently required, and these are covered by B.S.I. specifications S.65 and S.81, the former calling for 145,000 to 155,000 psi. and the latter 145,000 to 170,000 psi., both with a minimum Izod value of 35 ft-lb. Again, careful steel making practice, particularly in the electric furnace, coupled in some cases with small additions of molybdenum, has resulted in considerably greater toughness than the specified impact value. The writer has seen numbers of results from such steels in which a tensile strength of 155,000 psi. has been associated with Izod values of 60 ft-lb. and over.

Perhaps one of the most striking advances in ductility and toughness has been shown in the air hardening nickel-chrome steels, which in the hardened and lightly tempered condition give tensile strengths of 225,000 psi. and over. B.S.I. specification 2.S.28 calls for this figure as a minimum, together with an Izod value of at least 15 ft-lb., two values not easy to obtain together unless the steel is well made and very clean. With advances in the art of steel making, still greater ductility and toughness may be obtained, as witness the following results from two casts of electrically melted steel:

	Cast A	Cast B
Tensile	242,000	236,000
Elongation	15.0	15.0
Reduction	48.5	48.5
Izod	43,43,41	43,42,42

Data in the last few paragraphs have referred to electrically melted steels. Extremely good results can be obtained from material made in the acid openhearth furnace — results, in fact, which would have been deemed almost impossible 10 or 15 years ago. The following figures, for example, refer to nickel-chrome-molybdenum steels produced in this manner and they indicate what can be done with careful steel making:

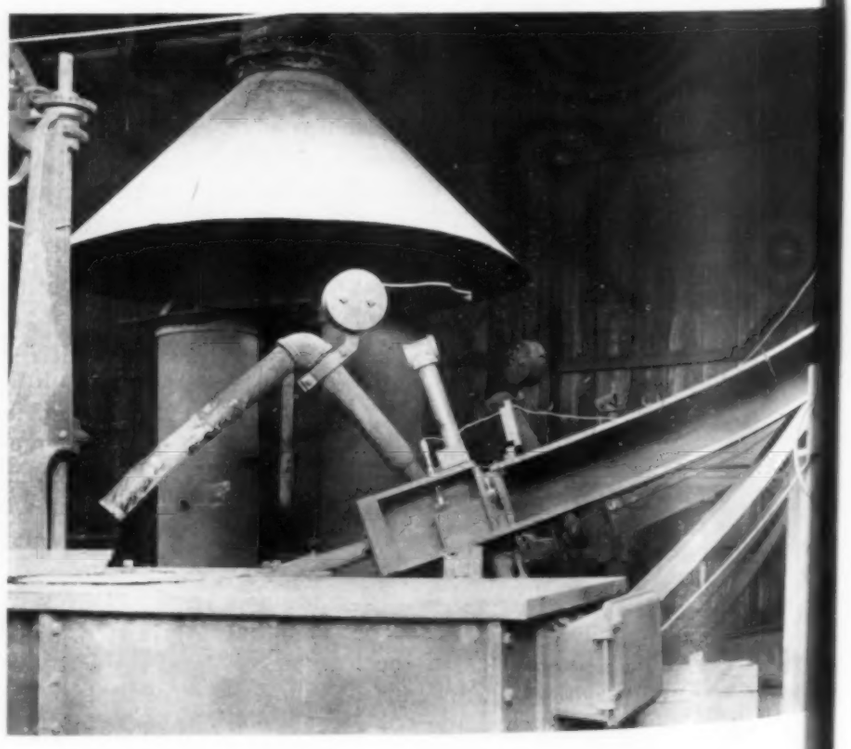
Ni-Cr-Mo Steels (Acid Openhearth)

Tensile	Elongation	Reduction	Izod
146,000	20.0	55.8	68
158,000	19.0	50.0	52
164,000	19.0	62.6	48
175,000	17.0	52.3	43
183,000	17.0	52.2	34
261,000	15.0	41.9	24

Summary

This brief review does not claim to describe all the trends in alloy steel development which may be observed in Great Britain. For example, there are steels having special properties for nitriding, for corrosion resistance and for heat resistance and those suitable for use at high steam temperatures, to name only some for which special properties are required and in all of which active progress is observable. To deal adequately with these would require an unduly long article and, hence, attention has been confined to noting the general trend of things in casehardening or high tensile steels — which, after all, may be regarded as forming the backbone of the alloy steel trade.

Original Taylor-White Pyrometer Box (Near Side Removed). Observer stood at right and looked through square hole in upper end of box and viewed hot surface of skimmed lead bath through pipe extending onward at left. He compared its color against a bottle of colored water, the latter illuminated by carbon filament lamp connected with a bank of wet batteries kept at constant voltage



Historical Development of High Speed

By H. C. Bigge
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Bethlehem Steel Co.
Bethlehem, Pa.

Contrast the Modern Optical Pyrometer and Ease With Which the Observer Takes the Temperature of Melted Toolsteel in a 1200-Lb. Induction Furnace With the Crude Equipment Used by Taylor and White (Shown Opposite)

FROM time immemorial man has made steel by fusing iron and charcoal in crucibles. Proofs of this are furnished by carvings and workings in hard stone which could not have been executed readily without steel tools. Archaeologists have discovered that the Chinese made steel in crucibles long before the Christian era. The old "Wootz" steel of India, as well as the celebrated Damascus and Toledo steels, were also crucible steels.

The modern toolsteel dates back to about 1740 when Huntsman, of Sheffield, England, revolutionized the old process by melting broken pieces of true steel (carburized or cemented iron) in crucibles, thus obtaining a more uniform metal.

Another important advance came with the Mushet "self hardening" steel, about 1870. After a long series of experiments Robert Mushet, manager of Titanic Steel Co. in England, discovered that the addition of a considerable quantity of tungsten to a steel, in combination with a higher percentage of manganese than had formerly been used, had a most peculiar effect. Tools made from such a steel became almost as hard by slow air cooling from forging heat as regular carbon tools quenched in water. On account of this peculiar property the English called it "self hardening" steel; in the United States the term "air hardening" was later adopted. Introduction of Mushet steel represented a great advance over ordinary crucible carbon steel, and for many years it held a foremost position among toolsteels the world over.

The next important advance came in the United States, shortly before the turn of the century. Credit for the present remarkable developments in toolsteels is chiefly due Fred W. Taylor and Maunsell White, who, at Bethlehem Iron Co., initiated high speed cutting.

In 1898 Bethlehem Iron Co., which a year later became Bethlehem Steel Co., found the machine shop incapable of handling the output of the forge shop. Much of the production was guns and armor, and required extensive and

accurate machining. The cost of a new machine shop of adequate capacity was estimated at one million dollars. At this juncture Mr. Taylor's success in increasing shop efficiencies at other plants induced the company to retain him to work on the problem.

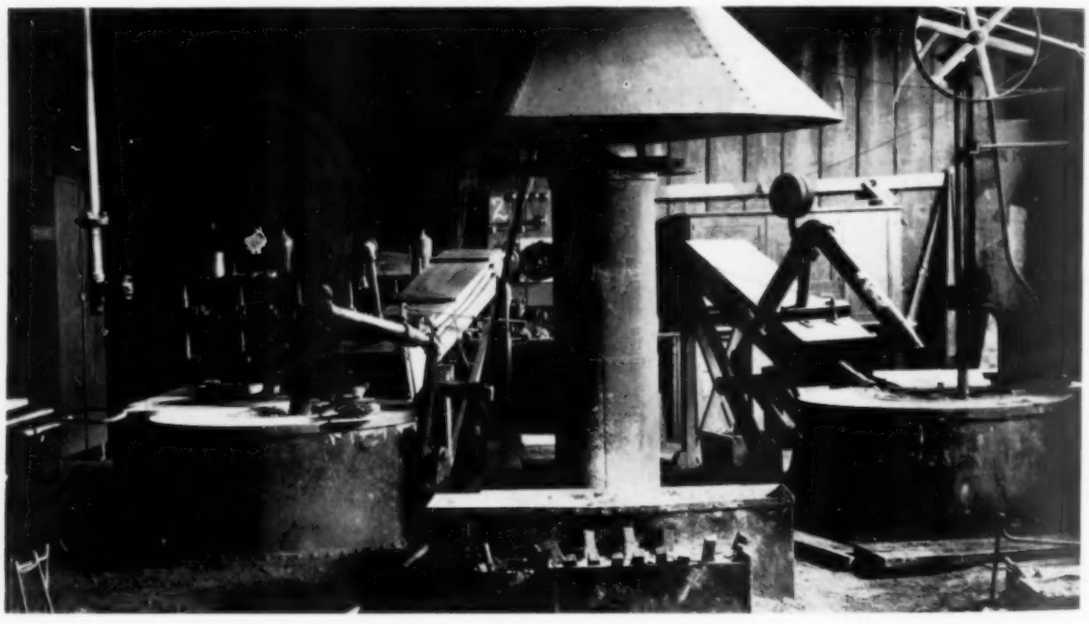
During the winter of 1894-1895 Taylor had conducted an investigation for Wm. Sellers & Co. and William Cramp & Sons, (important Philadelphia firms, machine tool manufacturers and marine engineers respectively) to determine the make of self hardening tool that should be standardized for all roughing tools in their shops. At that time the choice narrowed down to two steels, Steel No. 1, Mushet steel, and Steel No. 2, a self hardening American steel. Their composition was as shown below:

	No. 1	No. 2
Carbon	2.15	1.14
Manganese	1.58	0.18
Phosphorus	—	0.023
Sulphur	—	0.008
Silicon	1.05	0.25
Chromium	0.39	1.83
Tungsten	5.44	7.72

Taylor heated hundreds of tools of these makes to determine the best temperature for forging and heating. He found tools made from Steel No. 2 capable of running at fairly high cutting speeds. Mushet steel, if overheated, crumbled badly even under a light blow on the anvil; Steel No. 2, on the other hand, showed no such tendency, but did seem permanently injured. In fact, heated slightly beyond a bright cherry red, tools from the latter steel lost their cutting speeds, and he was unable at that time to find any heat treatment capable of restoring them to their original condition. This defect left him in doubt which was the better to adopt as a standard.

In the summer of 1898, soon after undertaking the reorganization of the Bethlehem machine shop, Taylor decided to continue these experiments to ascertain if, in the meanwhile, some better toolsteels had not been developed. These experiments indicated that the tools made from Steel No. 2, if properly heated, could run at slightly higher speeds than any other.

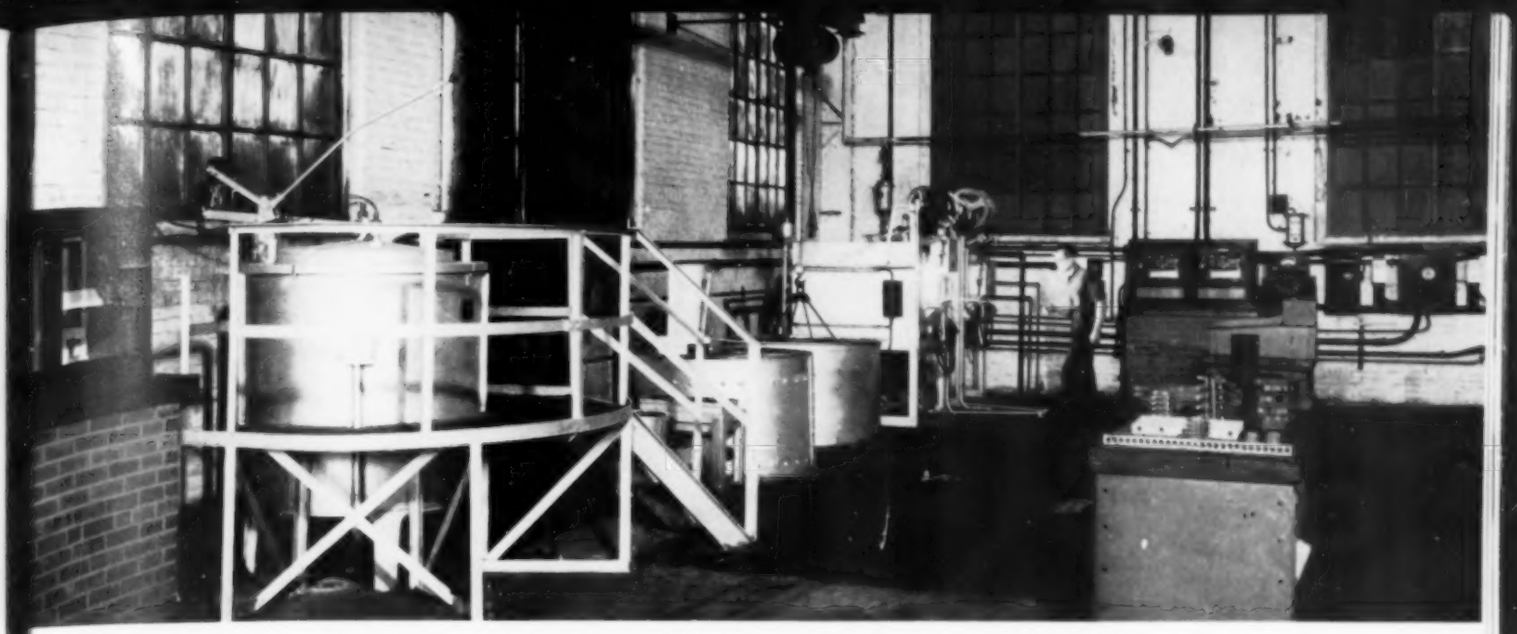
Experimental Laboratory in Which High Temperature Treatment Was Discovered



Two coal-fired lead pots, one for quenching and one for drawing; when temperature ran too high, the molten lead was cooled by compressed air through counterweighted and hinged U-pipes. Note pyrometer boxes at rear. Tools were first preheated in a forge, then plunged into high temperature bath (left) by special tongs. In the drawing bath (right) they were fastened to a plunger and slowly turned by belt-driven pulley

After deciding to adopt Steel No. 2 as standard he had a number of tools of each steel carefully dressed and ground to exactly the same shape. He then called the machine shop foremen and superintendents to the experimental lathe, to convince them by actual demonstration that Steel No. 2 was, on the whole, the best. However, this steel actually proved the worst, running at slower cutting speeds than any of the others!

This humiliating result was first blamed



Modern Heat Treatment Department for Tool Treatment and Semi-Commercial Experimentation (Bethlehem Steel Co.)

on overheated tools. Careful inquiry in the smith shop revealed that special pains had been taken to dress the tools at low heat, although the matter was left in much doubt. Taylor therefore determined to make a more thorough investigation to discover, if possible, some heat treatment which would restore the injured tools (whether underheated or overheated) to their original good condition.

For this reason Taylor and White started a carefully planned series of experiments, heating tools at temperatures increasing by about 50° increments, from a black heat to the melting point. The tools were then ground to shape and run in the experimental lathe to determine:

1. The heat treating temperature giving highest cutting speed (in previous experiments shown to be a cherry red).

2. The exact danger point at which the tools, if overheated or underheated, were seriously injured.

3. The heat treatment capable of restoring injured tools to their former cutting speed.

These experiments corroborated the Cramp-Sellers results, showing that the tools were seriously injured or broken down by overheating somewhere between 1550 and 1700° F. But to their great surprise they found that tools heated to or above 1725° proved better than any of those treated at the temperature formerly considered the best — a bright cherry red. And from 1725° and up to incipient melting, the higher the temperature, the greater the cutting speeds obtained!

Thus the discovery that phenomenal results could be obtained by heating tools close to the melting point — something completely revolutionary and directly opposite to all previous treatments — was the indirect result of a well planned, scientific effort to determine which brand of toolsteel was best suited for a shop standard. Neither Taylor nor White had the slightest idea that overheating beyond bright cherry red would do anything except injure the tool more and more the higher the temperature.

At the Paris World Exposition, in 1900, Bethlehem Steel Co. gave the first public demonstration of toolsteels possessing what was then considered most extraordinary cutting speeds. It is worth while to quote a contemporary report, printed in *The Engineer* for Sept. 7, 1900, page 232:

"The Bethlehem Steel Co. of South Bethlehem, Pa., is doing some remarkable work in the way of cutting steel at the Vincennes Annexe, Paris Exhibition. They show a steel roll being turned in a lathe in order to illustrate the quality of the steel from which the cutting tool is made . . . The process imparts such an extraordinary toughness to the steel that the tool will work dry at a very high temperature, and, in fact, will perform equally well when red hot as when cold . . .

"It is claimed that while a tool treated by the Taylor-White process will cut mild steel at the rate of 150 ft. per min., the rate of cutting medium hard steel is 60 ft., and of very hard steel 15 ft. . . . During the twelvemonth that the tools have been in practical use in the three machine shops of the Bethlehem Steel Co., where a considerable quantity of guns, armor plates and marine shafting are manufactured, the average cutting speed per minute has, it is said, been increased from 9 to 25 ft., the average depth of cut from 0.23 to 0.3 in., and the average feed from 0.07 to 0.087 in. The average quantity of metal removed per hr. has augmented from 31.18 lb. to 137.3 lb., thus showing a gain in actual work of 340% . . ." *(Cont. on page 460)*

Classification of American Toolsteels — I

Adapted from Tool Steels, by James P. Gill

General Purpose Carbon Toolsteels

Water hardening; low wear resistance; high warpage; no red hardness; shallow hardening

Carbon	Silicon	Manganese	Sulphur	Phosphorus	Vanadium	Common Uses
0.60-1.25 (a)	0.15-0.50	0.10-0.35	0.03 max.	0.03 max.	Note (b)	Almost universal; note (c)

(a) Usually subdivided by 0.10% steps; for instance 0.65-0.75%, 0.75-0.85%, etc.

(b) Plain carbon steels have no vanadium; carbon-vanadium tool steels may have from 0.08 to 0.40% vanadium, depending on grade.

(c) In lower carbon ranges the steels make shear blades, hammers, striking dies, rock drills. In medium ranges of carbon, the steels make chisels, smith's tools, dies, and cutters for machine tools. In the higher ranges of carbon are small cutters, wood workers' tools and cutlery.

Chromium-Vanadium or Low Chromium Toolsteels

(Substitutes for carbon tool steels)

Mostly water hardening; low wear resistance; high warpage; no red hardness; medium deep hardening

Carbon	Silicon	Manganese	Chromium	Vanadium	Remarks
0.50-1.40	0.15-0.50	0.10-0.35	0.10-0.25	.....	Chromium corrects tendency toward soft spots
0.50-1.40	0.15-0.50	0.10-0.35	0.25-0.50	.....	More intense hardness
0.50-1.40	0.15-0.40	0.10-0.35	0.60-1.20	0.10-0.20	Water hardening } Very tough in low carbon ranges
0.50-1.40	0.15-0.40	0.40-0.60	0.60-1.20	0.10-0.20	Oil hardening }

High Carbon, Low Tungsten Tool and Die Steels

(Finishing tools for hard steels or non-ferrous alloys)

Oil hardening; medium wear resistance; medium toughness; low warpage; no red hardness; medium deep hardening

Carbon	Silicon	Manganese	Chromium	Tungsten	Vanadium (Optional)	Remarks
0.90-1.10	0.20-0.40	0.15-0.30	.....	1.00-1.50	.....	Somewhat erratic in heat treatment
1.15-1.25	0.20-0.40	0.15-0.30	.....	1.75-2.50	0.10-0.25	
0.90-1.10	0.20-0.40	0.15-0.30	0.35-0.75	1.50-2.50	0.10-0.25	Water hardening } more dependable
1.15-1.30	0.20-0.40	0.15-0.30	0.35-0.75	1.50-2.50	0.10-0.25	Oil hardening }

Manganese Oil Hardening Die Steels ("Non-Deforming")

(General purpose tools and especially dies, punches and broaches)

Oil hardening; low wear resistance; medium toughness; low warpage; no red hardness; medium deep hardening

Carbon	Silicon	Manganese	Chromium	Tungsten	Molybdenum	Vanadium	Remarks
0.85-0.95	0.20-0.40	1.50-1.75	.....	.....	.....	0.10-0.25	More subject to grain growth
0.85-1.00	0.20-0.40	1.15-1.45	0.30-0.60	0.30-0.60	.....	0.10-0.25	Corrects above, but hardness is lower
0.85-1.00	0.20-0.40	1.35-1.65	.....	.....	0.20-0.35	0.10-0.25	Attains highest hardness
0.90-1.00	0.20-0.40	0.90-1.15	0.50-0.90	.....	.....	.....	Least susceptible to hardening cracks

Tungsten Alloy Chisel and Punch Steels (Small Deforming)

(Oil hardening steels; shears and battering tools for cold metal; heading dies)

Medium wear resistance; high toughness; low warpage; medium red hardness; medium deep hardening

Carbon	Tungsten	Chromium	Vanadium	Silicon	Remarks
0.45-0.60	0.75-1.25	0.75-1.25	.....	1.00-1.50	Good wear resistance but somewhat brittle
0.45-0.60	1.50-2.00	0.75-1.25	.....	1.00-1.50	Higher tungsten improves wear resistance
0.45-0.60	1.00-1.75	0.50-1.00	.....	.....	Low silicon increases toughness 25%
0.40-0.55	1.75-2.25	0.75-1.25	0.10-0.30	.....	Most popular analyses, tough and fine grained
0.55-0.65	1.75-2.25	0.75-1.25	0.10-0.30	.....	

Tungsten Finishing Toolsteels and Drawing Dies

(Brittle but intensely hard and keen edges for cutting hard materials)

Water hardening; medium wear resistance; low toughness; high warpage; no red hardness; deep hardening

Carbon	Tungsten	Chromium	Remarks
1.20-1.40	5.00-6.00	.....	Slightly better wear resistance than lower tungsten
1.20-1.40	3.00-5.00	.....	Slightly tougher than higher tungsten
1.20-1.40	4.00-6.00	0.40-0.80	Chromium improves heat treatability and reduces volume change
1.20-1.40	4.00-6.00	1.00-1.50	

Silicon-Manganese Punch and Chisel Steels

(A water hardening and inexpensive steel for cold cutting)

Medium wear resistance; medium toughness; medium warpage; medium hot hardness; medium deep hardening

Carbon	Silicon	Manganese	Chromium	Molybdenum	Vanadium	Remarks
0.50-0.60	1.80-2.20	0.60-0.90	.....	.....	.....	Spring steel analysis; all high silicon steels liable to soft skin
0.60-0.75	1.70-2.25	0.70-0.90	.....	.....	.....	More carbon gives higher hardness
0.50-0.60	1.75-2.25	0.70-0.90	0.20-0.35	.....	0.15-0.30	Alloys increase hardenability and refine grain
0.50-0.60	1.75-2.25	0.70-0.90	.....	0.40-0.60	.....	Molybdenum greatly increases hardenability
0.50-0.60	0.75-1.25	0.35-0.60	0.20-0.40	0.40-0.60	.....	Low silicon reduces brittleness and wear resistance

Classification of American Toolsteels — II

Adapted from Tool Steels, by James P. Gill

High Carbon, High Chromium Punch and Die Steels

(Durable rolls, mandrels, punches, dies and shears for cold work)

High wear resistance; low toughness; low warpage; high hot hardness; deep hardening, difficultly machinable

Carbon	Chromium	Vanadium	Molybdenum	Cobalt	Nickel	Remarks
			Oil Hardening Types			
2.25-2.45	12.00-14.00	.....	.....	.....	.....	
2.10-2.20	12.00-14.00	0.75-1.00	.....	.....	.....	Somewhat tougher
2.15-2.25	12.00-14.00	.....	.....	.....	0.50-0.75	Slightly air hardening; most difficult to machine
2.15-2.25	12.00-13.00	0.75-1.00	.....	0.60-1.00	.....	Slightly red hard
			Air Hardening Types (Tougher Than Above; "Non-Deforming")			
1.40-1.50	12.00-13.00	.....	0.50-0.60	3.00-4.00	.....	Sometimes used for cutters in machine tools
1.50-1.70	16.50-18.00	.....	.....	.....	.....	Liable to harden non-uniformly
1.50-1.60	12.00-13.00	.....	0.80-1.00	.....	.....	
1.50-1.60	12.00-13.00	0.80-1.00	0.75-0.90	0.40-0.60	.....	Vanadium imparts greater toughness
1.40-1.55	12.00-13.00	0.80-1.00	0.75-0.90	.....	0.60-0.80	Most difficult to machine

Chromium Die Steels for Hot Work

(Gripper, bending and heading dies for light work up to 600° F.)

Air or oil hardening; medium wear resistance and toughness; low warpage; medium hot hardness; deep hardening

Carbon	Chromium	Molybdenum	Remarks
0.85-1.00	3.75-4.00	.....	Usually quenched in light air blast
0.85-1.00	3.25-3.75	.....	Lower chromium reduces cracks during oil quenching
0.65-0.75	3.75-4.25	.....	Oil quenching (lower carbon) but not as rigid at 500° F.
0.85-1.00	3.75-4.25	0.40-0.60	Best air hardener

Tungsten Die Steels for Hot Work

(Blanking, forming, extrusion and casting dies to work up to 1100° F.)

Air or oil hardening; medium wear resistance; medium toughness; low warpage; high red hardness; deep hardening

Carbon	Tungsten	Chromium	Vanadium	Remarks
0.25-0.35	8.00-10.00	2.50-3.50	0.30-0.60	In most general use; serviceable up to 1000° F.
0.35-0.45	8.00-10.00	2.50-3.50	0.30-0.60	Higher carbon gives higher hardness
0.40-0.50	9.00-12.00	1.25-1.75	.....	Chromium lowered to increase toughness
0.25-0.35	12.00-16.00	2.50-3.25	0.30-0.60	Increased tungsten raises serviceability to 1100° F.
0.35-0.50	12.00-16.00	2.50-3.25	0.30-0.60	Hardenability and brittleness rises with carbon content
0.50-0.60	12.00-16.00	2.50-3.25	0.30-0.60	
0.50-0.60	17.00-19.00	3.00-4.50	0.60-1.20	Low carbon, high speed steel

Tungsten-Chromium Steels for Hot Work and Die Casting Dies

Air or oil hardening; medium wear resistance; good toughness; low warpage; high red hardness; deep hardening

Carbon	Tungsten	Chromium	Vanadium	Molybdenum	Silicon	Remarks
0.40-0.50	6.50-7.50	6.50-7.50	0.20-0.60	.....	0.80-1.00	Maximum alloy for hottest services (900° F.)
0.35-0.45	5.50-6.50	5.00-6.00	.....	.....	0.80-1.00	Tougher but serviceable temperature lower
0.30-0.40	0.75-1.25	4.50-5.00	.....	1.00-1.50	0.80-1.00	Less expensive substitute
0.40-0.50	1.50-2.50	1.00-2.00	.....	.....	.....	A tungsten alloy chisel steel

High Speed Steels

(Cutting tools of all types; tools for severe hot work)

Air or oil hardening; high wear resistance; low toughness; low warpage; high red hardness; deep hardening

Carbon	Tungsten	Chromium	Vanadium	Molybdenum	Cobalt	Remarks
			Conventional Types			
0.55-0.75	17.00-19.00	3.50-4.50	0.75-1.25	.....	.....	Most used; brittleness and cutting properties vary directly with carbon content
0.55-0.75	19.00-21.00	3.75-4.50	0.75-1.25	.....	.....	Better cutting ability but more brittle
0.75-0.85	17.00-19.00	3.50-4.50	1.75-2.25	0.40-0.90	.....	Best cutting ability; excellent for finishing cuts
0.55-0.75	13.00-15.00	3.50-4.50	1.75-2.25	.....	.....	Roughing tools; somewhat erratic in hardening
			Molybdenum High Speed Steel			
0.60-0.85	1.00-2.50	3.50-4.50	0.75-1.25	6.00-8.00	.....	Less expensive; "strategic" alloying element used
0.70-0.90	.....	3.50-4.50	1.75-2.50	6.00-9.00	.....	Improved by high vanadium content
			Cobalt High Speed Steel			
0.65-0.80	17.00-19.00	3.50-4.50	0.75-1.25	.....	3.50- 5.00	For cutting hard, gritty or tough materials
0.65-0.80	17.00-19.00	3.50-4.50	1.50-2.25	0.50-1.00	6.00- 9.00	Cutting ability varies as total alloy content
0.65-0.80	18.00-21.00	3.50-4.50	1.75-2.25	0.50-1.00	10.00-13.00	Maximum alloy to be forgeable
0.65-0.80	12.00-15.00	3.50-4.50	1.75-2.25	.....	5.00- 8.00	

Stages in the Development of Modern High Speed Steel

	Carbon	Manganese	Phosphorus	Sulphur	Silicon	Chromium	Tungsten	Vanadium	Speed (a)
Carbon steel	1.05	0.19	0.017	0.017	0.21				16
Mushet steel	2.15	1.58			1.04	0.40	5.44		26
Original Taylor-White steel	1.85	0.30	0.025	0.030	0.15	3.80	8.00		60
Best high speed steel (1906)	0.67	0.11			0.05	5.47	18.91	0.29	99

Note (a): Taylor cutting speed for medium steel in ft. per min.

The year 1900 may well be accepted as a milestone in metallurgy. Introduction of high speed steel led to a new art, the art of high speed turning and cutting, and recreated the machine tool industry. At the beginning of the century no high speed steels, as we now know them, were in existence. Electric furnaces for the production of steel were unknown in this country; vanadium was a chemical curiosity. The microscope, as an aid in research, was rarely used, and the information thus obtained was generally not highly regarded. Pyrometers were scarcely seen in the plants, and were not even common in laboratories. In fact, laboratory work consisted principally of routine chemical analysis, and metallurgists as we know them today did not exist. Most of those with metallurgical knowledge had acquired it by practical experience in the mills themselves, with or without a prior knowledge of chemistry. Nevertheless, these men, Taylor, White and their associates, produced real results because they had trained their powers of observation to an unusual extent.

With the introduction of the Taylor-White process cutting efficiencies increased from 100 to 200%. In the Bethlehem shop the use of this steel, combined with Taylor's improved production methods, resulted in an increase in production of about 500%; instead of adding to the machining facilities it was found necessary to expand the forge shop!

Evolution of Present-Day Analyses

Chemical analyses of four steels, typical of the various steps or epochs in the development of metal cutting tools, are presented in the adjoining table. The first in the list is the ordinary toolsteel of the carbon tool era; it still is very widely used for hand tools and light machine work. Number two is a typical self hardening steel as used by Taylor and White in 1894 and 1895; its modern prototype, with about half the carbon, is found in fast finishing tools. The third, the analysis recommended in their U. S. patent 668,270 of Feb. 19, 1901, marks the beginning of "high speed" or "red hard" tools and is a transition type of No. 4, which represents the best high speed steel up to the fall of 1906, when the results of Taylor and White were published in *Transactions* of American Society of Mechanical Engineers, Vol. 28, "On the Art of Cutting Metals."

Later developments in the chemical analysis will be described in a subsequent article. Here it may be said that the most popular high speed steels, now used for cutting tools of all types, are of the 18-4-1 type, or in round numbers 18% tungsten, 4% chromium and 1% vanadium. It can be seen how near the optimum composition these pioneers had reached by 1906.

First Public Showing of High Speed Steel by Bethlehem Steel Co. at Paris Exhibition, 1900

Methods of manufacture have undergone more radical changes. Our own operations may be briefly mentioned as indicative:

Our toolsteel department dates back to 1895. Originally a four-pot crucible furnace was used, with the pots embedded in anthracite; later, coke was used for heating. This is the furnace in which Taylor and White made the first high speed steels. It soon became necessary to increase the melting capacity, and in 1900 two new furnaces were installed, each of 30-pot capacity. These were of the regenerative type, fired with producer gas made from anthracite coal. No further change of real importance took place until 1907 when two additional furnaces, of the same capacity and construction, were installed.

Work on the foundation of a 10-ton Girod basic electric arc furnace was begun in 1912, and actual smelting operations were started the following year. This furnace was used for ordinary toolsteel only.

Two Heroult electric arc furnaces were installed in 1914, one of three tons, the other of six tons capacity. Both of these had basic linings and produced carbon toolsteel. Experiments with the production of high speed steel in the smaller Heroult furnace, in 1918, proved so successful that all crucible melting was discontinued the following year. In 1926 the six-ton Heroult furnace was replaced by a six-ton Lectromelt arc furnace. The Girod furnace was taken out of service the same year.

Melting in induction furnaces in our shop dates back to August 1929, when a coreless, high frequency induction furnace of 17-lb. capacity was installed. This small furnace was equipped with a 35-kva. spark gap converter and operated at frequencies of 15,000 to 45,000 cycles. Results obtained in this experimental unit were so encouraging that four furnaces, each of 600-lb. capacity, were installed in November of the same year. These operated at a frequency of 1000 cycles. A year later two of these were replaced by two 1200-lb. furnaces.

A five-ton oil-fired furnace, of special design, was installed in May 1935, for the manufacture of corrosion resisting steels.

The Way They Show Today! Booth in 1935 Metal Exposition with working models of automatically controlled heat treatment units

Approximate Critical Temperatures for S.A.E. Steels

by M.J.R. Morris, R. Sergeson and G.W. Gable; Central Alloy Division, Republic Steel Corp.

In most instances found by examining microstructure of quenched 3/8-in. discs of 1-in. round, taken from furnace at 20°F. increments. Grain size of steel unknown. Rate of heating and cooling about same as in furnace-cooling for commercial annealing

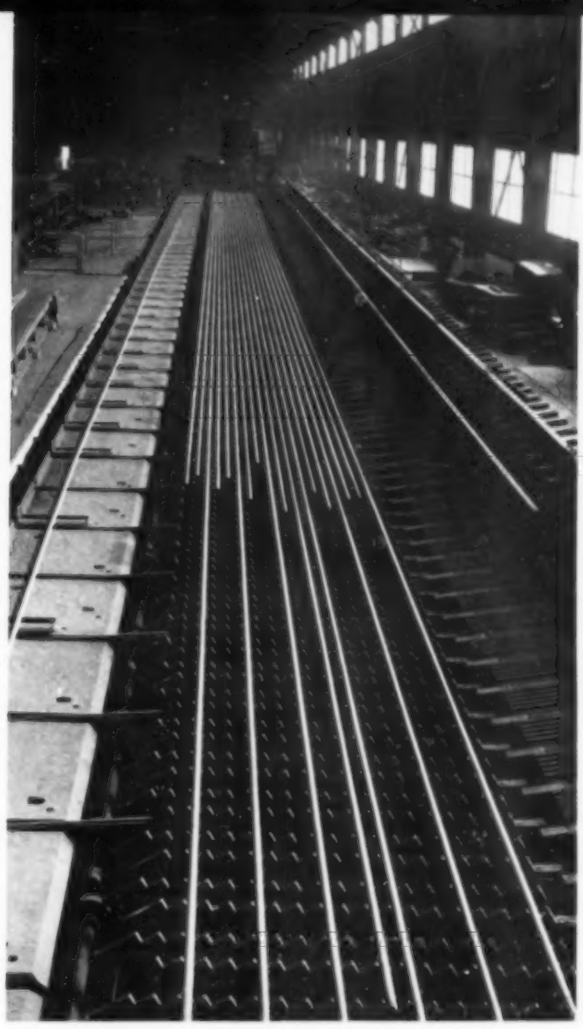
Number	On Slow Heating			On Slow Cooling		
	Ac_1	Ac_2	Ac_3	Ar_3	Ar_2	Ar_1
Carbon Steels						
1010	1350	1405	1605	1570	1400	1255
1015	1355	1410	1585	1545	1395	1265
X1015						
1020	1355	1410	1570	1535	1395	1260
X1020						
1025	1355	1405	1545	1515	1405	1255
X1025						
1030	1350	1405	1495	1465	1405	1250
1035	1345		1475	1455	1395	1275
1040	1340		1455	1415		1275
X1040	1340		1450	1340		1270
1045	1340		1450	1405		1275
X1045	1335		1420	1330		1270
1050	1340		1425	1390		1275
X1050	1335		1400	1330		1270
1055	1340		1425	1390		1275
X1055	1335		1400	1330		1270
1060	1340		1410	1370		1275
1065	1340		1385	1345		1285
X1065	1335		1380	1330		1280
1070	1345		1370	1340		1280
1075	1350		1365	1340		1280
1080			1360	1285		
1085						
1090			1360	1285		
1095			1360	1290		
10150*			1355	1290		
Free Cutting Steels						
1112	1355	1410	1590	1545	1395	1265
X1112						
1115						
1120	1355	1405	1550	1510	1400	1255
X1314						
X1315	1345	1420	1520	1495	1370	1245
X1330						
X1335						
X1340						
Manganese Steels						
T1330	1325		1480	1340		1160
T1335	1315		1460	1340		1165
T1340	1315		1435	1310		1160
T1345	1315		1410	1300		1160
T1350	1310		1400	1255		1105
T1360*	1305		1405	1200		1095
Nickel Steels						
2015	1375	1475	1575	1450	1400	1215
2115	1345	1455	1525	1475	1380	1195
2315	1300	1350	1440	1350	1260	1100
2320	1285	1345	1420	1235	1160	920
2330	1275	1315	1400	1180		1050
2335	1275		1375	1180		1050
2340	1280		1360	1180		1060
2345	1280		1350	1180		1060
2350	1280		1340	1180		1070
2515	1250	1335	1420	1220	1140	825
2520*	1240	1340	1390	1175	1025	825

*This number not in the official S. A. E. list

Number	On Slow Heating			On Slow Cooling		
	Ac_1	Ac_2	Ac_3	Ar_3	Ar_2	Ar_1
Nickel-Chromium Steels						
3115	1355	1400	1500	1470	1380	1240
3120	1350	1400	1480	1455	1380	1230
3125	1350	1395	1465	1400	1380	1220
3130	1345	1380	1460	1360		1220
3135	1340		1445	1300		1220
3140	1355		1415	1295		1220
X3140	1350		1430	1300		1240
3145	1355		1395	1295		1220
3150	1355		1380	1275		1215
3215	1350	1410	1465	1415	1350	1240
3220	1350	1415	1460	1405	1355	1240
3230	1340		1435	1395		1240
3240	1335		1425	1280		1240
3245	1345		1400	1270		1225
3250	1340		1375	1255		1200
3312	1330	1370	1435	1240		1160
3325	1335	1365	1400	1230		1160
3330*	1320	1360	1380	1225		1145
3335	1310		1360	1200		1100
3340	1290		1380	1180		1100
3415	1330	1370	1425	1340	1300	1220
3435	1290		1380	1200		1150
3450	1290		1360	1200		1100
Molybdenum Steels						
4130	1395	1435	1485	1405	1395	1280
X4130	1395	1435	1480	1405		1250
4135	1395	1440	1475	1380	1360	1280
4140	1380		1460	1370		1280
4150	1365		1395	1355		1280
4340	1350		1425	875		725
4345	1345		1415	875		725
4615	1335	1400	1485	1400	1320	1200
4620	1335		1470	1390		1175
4640	1320		1430	1300		1125
4650*	1315		1410	1260		1125
4815	1300		1440	1310		800
4820	1300		1440	1260		760
Chromium Steels						
5120	1410	1460	1540	1470	1420	1295
5140	1370		1440	1345		1280
5150	1330		1420	1280		1220
52100	1340		1415	1315		1280
Chromium-Vanadium Steels						
6115	1420	1460	1550	1450	1380	1300
6120	1410	1460	1545	1440	1380	1300
6125	1400	1440	1490	1390	1360	1295
6130	1390	1440	1485	1370	1340	1285
6135	1390		1480	1370		1280
6140	1390		1455	1375		1295
6145	1390		1450	1375		1290
6150	1385		1450	1375		1270
6195	1370		1425	1360		1300
Tungsten Steels						
7260	1360		1430	1370		1310
Silicon-Manganese Steels						
9255	1400		1500	1380		1320
9260	1400		1500	1380		1315

Trends in Alloy Steels in America

By Ernest E. Thum
Editor, Metal Progress



Mechanical Bed for Cooling and Maintaining Straightness in Bars While Transferring From Run-Out to Delivery Tables. Photos Courtesy Timken Steel & Tube

A COMPLETE review of the trends in American practice concerning alloy steels should rightly start 50 years back when alloys were almost entirely restricted to the field of toolsteels, grinding equipment, armor plate and projectiles. Five families of alloy steels were even then established as follows, in order of priority, nickel having but recently been studied (1889): 1. Chromium steel by Bauer, for hard items such as grinding balls, cell bars, safes, projectiles. 2. Tungsten steel (in combination with manganese) by Mushet for self-hardening toolsteel. 3. Manganese steel by Hadfield, for hard, wear resisting parts. 4. Silicon steel, also by Hadfield, later to be so important to electrical machinery. 5. Nickel steel, by Riley, for items requiring great strength and toughness, such as large shafting, armor plate and members for long-span bridges. The latter, made into pins and links for bicycle chains is said to be the first alloy steel application in that industry which was the forerunner to the automobile industry in mass production. Exactly 30 years ago vanadium steels were produced in an American openhearth furnace, and there remained only molybdenum to complete our present cast of characters. Molybdenum was a War baby, so to speak, for a Wartime demand was responsible for the development of American deposits of commanding importance and a vigorous program of experimentation and exploitation.

With these seven alloying metals, each with its own definite personality, an almost infinite number of combinations and permutations is possible with steels of various carbon compositions. Herein lies the reason for a most evident trend in American alloy steels — namely, its enormous diversity. That there is *any* standardization in chemical compositions is undoubtedly due to the efforts of the automotive industry, which organized work along this line at least 30 years ago.

At that time alloy steels were available from a number of manufacturers, but were sold under trade names, and whenever a user changed his supplier, he perforce changed the nature of his steel! To avoid this, the first list of compromise chemical analyses was published by the automo-

tive industry in 1911; it contained seven carbon steels and 11 alloy steels.

This nowhere near covered the useful steels then in vogue. Diversification also was proceeding apace, and we find the S.A.E. list issued in 1922 containing 68 different analyses, a figure which was completely overshadowed by the current list issued in 1935 (see page 449), which totals no less than 109.

Even this is not sufficient, for it does not contain the carbon-molybdenum steels (now being used in considerable tonnage), various members of the individual families whose alloy content is either lower or at different proportion from that given in the S.A.E. list, and a number of alloys used principally in other industries such as the railroad. Then there is also the series of low alloy steels or strong structural steels which have recently appeared — at least one for each important steel producer!

Varieties Too Numerous

It is not necessary to list all these steels to infer that their number is all too many. A simplification undoubtedly would lower costs, not only in manufacturing, but also in stocking and accounting in the customer's plant. Considerable diversification in the S.A.E. list is necessary to provide alternative compositions, not only to avoid discrimination against one or more manufacturers, but also to provide at least two different analyses for almost any desired combination of physical properties. Sharp competition during depression years introduced the era of "tailor-made steels" (in Mr. Girdler's apt phrase). If the customer's metallurgist and purchasing agent insist hard enough, and the order is big enough, the steel companies even in today's relative prosperity will do something about it.

The situation is exemplified in one of the important automobile plants. Here there are no less than three kinds of S.A.E. 1045 steels in production. The first might be called the common or garden variety of 1045, conforming to the S.A.E. chemical specifications with fairly wide spread in carbon and manganese content. It can be normalized for excellent machinability and is put into minor parts. The second type is ordered to grain size No. 5 to 7, and made into such things as flywheel ring gears, which are oil quenched after machining and which naturally require a minimum dimensional change during heat treatment. The third type is made into crankshafts and connecting rods carrying moderate unit stresses, and it is ordered to a coarse grain specification and a special etch test so that the forging will have "fiber" or "openness," which is believed to improve machinability.

A second trend is toward the low alloy varieties. To appreciate this we can cast our mind back to the reason for using alloy steel in the first place. Carbon steel, wrought iron and castings were good enough for machinery in olden days. It was operated at a slow rate, and if certain parts broke in service, they could be made large enough until they stood up. As more speed and less weight came to be required, alloy steel came to be used in the highly stressed parts in order to compensate for poor workmanship, poor design, excessive deflections, and mis-aligned bearings. Practically all designing was based on high physical properties, and the 3½ and 5% nickel steels and the high nickel-chromium analyses stepped into the breach.

(It is, of course, true that proper alloying mitigated or entirely eliminated the mass effect, and the high alloys will always be used for relatively massive parts. The discussion which follows is confined to trends in the much more numerous parts, weighing a few pounds at the most.)

Harry McQuaid is fond of saying that 95% of the metallurgical troubles are problems in mechanical engineering. That merely is an indication that modern machinery has been vastly improved in *design*. Even though the over-all stresses carried by a given part are higher, transmitting more horsepower at a higher speed, the *maximum* or concentrated stress has been lowered. In the case of a gear, for instance, the alignment of the bearings has been improved and made permanent, the form of the teeth has been changed from point contact to line contact, accurately cut to insure low tooth stresses.

Trend Toward Low Alloys

With elimination of all sorts of "stress raisers," the metallurgist gradually decreased the total alloy content in the part, or modified it by using cheaper alloys. Maximum stresses in well-designed parts are low enough to be carried by the cheap alloy steels, if they are properly made, even the plain carbon steels were it not necessary to quench in oil to avoid warpage, straightening troubles and damage thereby, to say nothing of quenching cracks.

Extras for Alloy Content; Cents per Pound

Extra During 1934 to 1936			Extra Established March 1937	
S.A.E.	Family	Extra	Steel	Extra
T-1320	Manganese	Base	T-1320	0.10
T-1315	Manganese	0.25	T-1315	0.35
C-Mo	(Mo 0.10 to 0.20)	0.20	5100 (low Cr)	0.25
	(Mo 0.15 to 0.25)	0.25	(medium Cr)	0.35
5100	(Cr less than 0.60)	0.25	(high Cr)	0.45
	(Cr 0.60 to 0.90)	0.35	C-Mo (low Mo)	0.35
	(Cr 0.80 to 1.10)	0.45	(high Mo)	0.40
4100	Cr-Mo (low Mo)	0.50	4100 (low Mo)	0.55
	(high Mo)	0.70	(high Mo)	0.75
3100	Ni-Cr		3100 (low Ni)	0.70
	(Ni 1.00 to 1.50)	0.55	(high Ni)	0.80
	(Ni 1.25 to 1.75)	0.65	4600	1.10
4600	Ni-Mo	1.05	6100	1.20
6100	Cr-V	1.20	2300	1.50
2300	3½% Ni	1.50	4345	1.65
4800	3½% Ni-Mo	2.00	4800	2.00
2500	5% Ni	2.25	2500	2.25
4345	Ni-Cr-Mo	2.30		

A timely advance in steel making has taken the place of some of the alloy which has been eliminated; this refers to hardenability control through grain size control. The fine-grained, low alloy steels, which can now be regularly produced even in the openhearth grades, can be made shallow hardening, tough and with a minimum of warpage after an oil quench.

In the small space available it is impossible to survey the field in a broad manner. Trends on automobiles, trucks, tractors and aircraft will indicate advanced practice, for metallurgists in those industries are leading the procession. General practice on passenger cars was outlined by William H. Graves in Metal Progress for April 1936. Three questions are to be asked in selecting a steel for a given part: First, how does it function in service? Second, how economical is the machining and other processing? Third, how much does it cost? Since six of the leading automobiles show no unanimity of selection of steels in any one of 15 or 20 important parts, considerable latitude is present as to the first question. As to the other two, the processing costs are so much greater than the bar costs that first attention is given to them, but that does not mean that the cost of the stock is not important. Mr. Graves' analysis of 20 parts, not including the crankshaft and camshaft, shows a maximum differential of $1.60 per car in raw material cost, cheapest to most expensive steel. While this does not sound like very much, it amounts to about $7,500,000 for the 4,600,000 cars produced last year — certainly a figure important enough to attempt to do something about.

The drive is therefore toward lower bar costs, if this can be achieved without unduly increasing other costs. What has already been achieved is eloquently shown by the steels Mr. Graves lists as being in use. All of them were carrying an extra of 0.50¢ per lb. or less, with the exception of the important gear steels S.A.E. 4600 (nickel-molybdenum for single quench) and 6100 (chrome-vanadium), then carrying an extra of 1.05 and 1.20¢ per lb. respectively. He notes that already the cheap carbon-molybdenum is being substituted for the latter.

Uses, therefore, and trends in uses in the production industry can be related to the extras which the steel mills believe necessary to charge for certain items. Recent changes in these extras are shown in the attached table and foreshadow important future trends. It will be observed that a couple of years ago the manganese and carbon-molybdenum steels could be grouped together as a lowest-priced group of alloy steels, the chromium steels S.A.E. 5100, chromium-molybdenum steels S.A.E. 4100, and nickel-chromium steels S.A.E. 3100 were the steels of medium cost, whereas the nickel-molybdenum 4600, chromium-vanadium 6100, and 3½% nickel 2300 were grouped together as fairly high cost alloys. The new list increased the base $11.00 and all the extras except for the plain chromium steels, and has therefore interchanged the relative position of plain chromium steels and carbon-molybdenum steels. It results that the plain chromium steels, with controlled grain size, will be increasingly used for important parts.

Mr. Graves in the article above mentioned thinks that the transmission gears of the future will have lower alloys and a carbon content between the present-day steel used for carburizing (0.20%) and that for the oil hardening grades (0.45 to 0.50%). For alloys these will contain molybdenum, chromium, or both so that they can be treated for a very hard, wear resistant surface. Grain size control will give an inherently tough core. A present case in point, which one car is already using, is 5130 for rear axle ring gears, or carbon-molybdenum steel for ring gear and pinion. In the present schedule, they carry an extra of only $7 or $8 per ton.

Much steel is being used so low in alloy as to hardly class as "alloy steel." For instance, there is a variety of S.A.E. 1020, where the manganese is increased considerably (to the 0.70 to 1.00 range), and which in the coarse-grained variety can be oil hardened. This is quite extensively used for such things as tractor gears; it possibly would be better to add a little molybdenum and perhaps 0.15% chromium, but this would require an alloy steel extra. As a matter of fact, openhearth steel containing nothing more than the "incidental alloys" picked up from the melting of scrap will contain enough nickel, chromium and molybdenum to give the characteristics of alloy steel, especially if manganese is slightly higher than usual. Such a steel with hardenability controlled by means of grain size control is now produced in considerable quantity and carries no extra other than an optional "hardenability extra." (Incidental alloys now to be expected run up to 0.20% chromium, 0.25% nickel, and 0.25% copper.)

Another aspect of the so-called tailor-made steel is the numerous extra-specification requirements which the purchaser now expects as part of alloy steel practice. Many heats of steel are accepted only after the most searching investigation as to grain size, normality and abnormality, inclusion count, freedom from banding (important in controlling distortion), and good homogeneity as shown by uniform deep etching (or contrariwise, a "fibrous" structure for improved machinability).

With all this diversity of materials available, we may expect to find a variety of steels in different plants for the same or quite similar parts. This is due to a number of different causes, among which may be mentioned different design of the parts, a considerable difference in the stresses the part carries, available tool setups, heat treating equipment, the cost of the raw steel, and even the accounting method. To these factors must be added the intangibles of personal preference, the sales drive by steel makers with a pet alloy, and the lack of accurate test data. Technical societies, such as the A.S.M. and the S.A.E., by bringing men from different plants together — both producers and consumers — are doing much toward ironing out these differences. As correct information is spread, the technical men tend toward a lower common denominator at a much more rapid rate.

Careful Cleaning of Surface Defects Before Final Rolling Is One Aspect of Alloy Steel Practice

Instrumentation: Exact Science Combined With Fine Art

By M. F. Behar and Richard Rimbach

Editor and Publisher, respectively, of "Instruments" Pittsburgh

Final Test and Calibration of a Dynagraph for Recording Instantaneous Loads and Velocities on Oil-Well Pumping Equipment. Courtesy Westinghouse Electric & Mfg. Co.

SO RAPIDLY have the successful uses of instruments multiplied in the metal industries since the World War that a complete table of the recognized applications — printed in small type — would fill the space allotted to this article.

You can verify this assertion for yourself by referring to your copy of the current ⊜ **Metals Handbook**: Pick out at random a few topical entries, select one you know, tabulate its instrument applications from memory, and multiply the number of lines in your own table by the total number of index entries pertaining to fields of work involving instruments — as estimated by yourself.

Consider also the fact that although the **Metals Handbook** is excellently compiled, a number of metallurgical subjects involving the use of instruments are not dealt with therein and its index does not list, for example, the very subjects with which the present authors could deal first of all in a systematic survey of all fields: Geophysics, Prospecting, Assaying, Mining, Concentration, Flotation, and so on. Nor does the **Handbook** cover the topics which would logically come at the end of such a methodical survey, such as automatic inspection and testing at the assembly-lines and on the packaging machines in the industries utilizing metals.

It is between the mines and the ultimate manufacturers' inspection departments, however, that the great majority of ⊜ members earn their bread and butter. Quite a distance between, in fact, for it is particularly in the field of heat treating that — for historical and other reasons — the keenest interest of the majority remains centered. A sure-fire instrument article, therefore, would deal only with recent commercial developments in furnace control; and since the authors regularly get all the commercial literature on furnace control — much of it excellently informative — they could easily put together a passable article, purely descriptive and perfectly safe.

But the Editor of **Metal Progress**, knowing that his readers already have access to various sources of these data, has asked for the background of the art, its trend and its future — in his own words: "How we got here and where we are going from here." In keeping with the future-facing keynote of this issue of **Metal Progress**, therefore, the authors will indulge in reminiscin' and preachin' and prophesyin', with which there will be interspersed some dry factual reporting, the idea being

not so much to stimulate interest but to widen its scope and perhaps to guide it.

As to historical lore, most of the strictly industrial instruments might be said to be devoid of it, for they are modern developments — some of them more modern than radio, as witness the remote-recording optical pyrometer. Does anyone remember the blackened resistor, total radiation receiver, in circuit with a delicate galvanometer, which was originated by Samuel Langley 50 long years ago and took 50 long minutes to read and had to be handled by a scientist? Contrast that with the photo-electric cell, a receiver of monochromatic light, in circuit with a standard illuminator and with a strip chart self-balancing recorder, which came out two short years ago and takes two short seconds to make a record and is used by a mill hand!

Origins of Modern Pyrometers

To be sure, many essential components of this and other modern industrial instruments do have a lot of historical lore back of them. The criterion is whether the central idea is of recent origin. Well, let us see. Thermal measurements of a sort were made by the ancients; Galileo built glass thermometers; Rey, Newton, Fahrenheit and Celsius successively advanced the art; Kelvin first approached a quantitative science by contributing his thermodynamic scale of absolute temperature; Kirchhoff defined the black body; Stefan conceived its fourth-power attribute and Boltzmann derived the fourth-power law; Wien then proposed the wave-length displacement equation and the energy distribution equation; Rayleigh and Planck re-wrote them as valid laws at the turn of the century; and Einstein finally verified them in 1916 and 1917.

Between 1879 and 1910, together with the advances in theory, there had appeared numerous types of optical pyrometers such as the extinction or wedge types, the divided-field illumination-matching type, the three filament-brightness-matching types, and various "color" types. But all of these optical pyrometry methods depended on the human eye. The idea of substituting for the human eye a light-sensitive device responding to one narrow wave band and calibrating it under the Wien-Planck fifth-power law could not have occurred until the appearance of photo-electric devices.

As to the switchboard type of electrical, self-balancing recorder, the first one was built by Professor Callendar of McGill University less than half a century ago and the first industrial model came out in Philadelphia a quarter-century ago. Calibration of the "eye" end did not become practicable, however, until calibrated photocells and phototubes were developed for talkies and television and until they could be sold with guarantees as to accuracy-life — which is so recent a practice that it still is the exception rather than the rule. The photocell output under monochromatic illumination being in the millimicrowatt range, an equipment suitable for steel mills had to embody fully developed, foolproof amplifying devices, and these did not appear until the radio industry had attained full growth.

All in all, the automatic optical pyrometer, or "optimatic" as it is called, is an assembly of five per cent of parts with an ancient history and ninety-five per cent of gadgets belonging to the streamline age — or, rather, the stainless-alloy age.

Equally modern are the automatic control instruments. Indeed, they may be said to be in their infancy or adolescence, because the underlying theories of automatic control have not yet been formulated mathematically. We do not mean to imply that the automatic control instruments now on the market are not fully developed in their physical forms, but we can safely assert that the study of their behavior — their "modes of control" as instrumenticians put it — has barely begun; and we venture to prophesy a relatively sudden two-fold increase in the application of automatic control systems to blast furnaces, openhearth furnaces and heat treating furnaces when theories will have been formulated and proved regarding the simultaneous control of several interdependent conditions or variables. This will not be a matter of instrument design. It will be instrumentation in its finest aspect — the apotheosis of "application engineering."

For if one thing is known about furnaces, smelting or refining furnaces, specifically, it is that nobody knows exactly what goes on during a heat or a campaign or a blow or a run; nobody knows exactly how each condition affects each other. At present it still seems like a vicious circle, because to study the effects of any change in one condition we must control it; and we can't control it without controlling all; and we can't control all without controlling each; and we can't control any physical or chemical variable without measuring it continuously or at frequent intervals; and we can't measure a variable without segregating and identifying it in order to make sure that it obeys some law of Nature that permits us to define a scale of its values and to design an *ad hoc* instrument; and so we can't do anything with complex phenomena perversely composed of vague and fugitive entities which elude us when we try to identify and measure them . . . as in a blast furnace or converter.

Of course it isn't so thoroughly vicious a circle as might be supposed from the above: Pouring temperatures can be measured with satisfactory accuracy, and even the temperatures of various interior points, zones or regions can be assumed to be represented by the millivolts generated by immersion thermocouples. We can accurately weigh

not only the solid materials but also the blast, and afterward we can analyze quantitatively the solid and gaseous products. In laboratories we also put minute samples in micro-furnaces and observe with our eyes various structural transformations as they occur at various temperatures, or we deduce them by magnetic effects, diffraction spectra and other physical properties. Thus, even though mysterious entities inside the furnace or converter still evade a metallurgical Sherlock Holmes, manual control of some external factors and automatic control of some others permit us to meet specifications and make sales to discriminating purchasers. But specifications have been growing more rigid and certainly will not grow less rigid in the future. Joint research by metallurgists, instrumenticians and other groups must and will segregate the elusive entities in the blast furnace and converter and identify them as measurable magnitudes. Then, and then only, will it be possible to develop a working theory for the simultaneous automatic control of the most important variables.

Blast Furnace Instrumentation

Meanwhile, without waiting for this day, specifications of increasing rigidity are being met, as mentioned above, by increasing the number of indicating, recording and controlling instruments applied to measurable and controllable conditions —conditions outside of the mysterious thermo-

Mostly for the Correct Handling of Hot Gases About a Modern Blast Furnace, no Less Than 34 Instrumental Control Stations Are Desirable. Photo by Henry M. Mayer

chemical processes but affecting their reproducibility. Nothing exemplifies the practical benefits of instrumentation more dramatically than its recent share in improving blast furnace economics. Practical men have found no less than 34 logical applications on shaft, stoves, and direct auxiliary equipment. Space precludes anything but the merest mention of the most important.

Automatic temperature control of the hot blast results in better furnace operation and steadier blast pressure. When the heated air passing through the tuyeres is held at the desired temperature, it tends to hold a constant condition at the zone of fusion. When this condition is constant, it results in a more uniform smelting of the ore. By smelting consistently at the same temperature, and at a constant rate, a more uniform iron is obtained. Operation of the furnace is smoother, with an increase in tonnage and a decrease in coke and in dust losses.

Hot blast control equipment is simple: A base-metal thermocouple is set in the blast main, usually just before it joins the bustle pipe, and connected to the control instrument which commands the mixer valve by means of a rugged servo-motor. A special recorder-controller makes small, gradual adjustments of the mixer valve as well as large adjustments. Its mode of control has two purposes: First, it holds the blast temperature at the control point within narrow limits; second, when a new stove goes on air and blast temperature shoots up, the controller's action brings it back rapidly toward the control point until it reaches a certain value above the control point, then eases it into the control band without overshooting.

This special controller deserves mention because it holds blast temperature within ± 8° F., and, when a new stove is put on air, returns the blast temperature to within this control band in 8 min. or less.

Openhearth Furnace Control

With respect to more "direct" automatic control, there are two typical examples of metallurgical furnaces — the openhearth furnace, and the heating furnace. In the past, automatic control usually applied to a single condition, gas pressure. Comparatively few installations were made in which the control of fuel supply, of furnace atmosphere and of furnace pressure was simultaneously effected. In some cases where ambitious schemes of regulation had been attempted, technical shortcomings in the equipment had prevented the expected results. Now, more adequate methods and equipment are available. An accurate estimate of the savings effected thereby is difficult, since no metallurgical operation is completely stable with respect to conditions other than those regulated.

Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys" Monograph No 1, British Institute of Metals

Element Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (note a)	Axial Ratio c÷a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter (Coordination No. 12)
Group IA in Periodic Sequence									
3 Lithium	(2)1	⊞	—	8	3.51±0.04	—	3.04	—	3.13
11 Sodium	(2)(8)1	⊞	—	8	4.30±0.04	—	3.72	—	3.83
19 Potassium	(2)(8)(8)1	⊞	—	8	5.333$_5$	—	4.618	—	4.76
37 Rubidium	(2)(8)(18)(8)1	⊞	—	8	5.62±0.03 at -173°C.	—	4.87 at -173°C.	—	5.02
55 Cesium	(2)(8)(18)(18)(8)1	⊞	—	8	6.05±0.03 at -173°C.	—	5.24 at -173°C.	—	5.40
87 Virginium	(2)(8)(18)(32)(18)(8)1	—	—	—	—	—	—	—	
Group IB									
29 Copper	(2)(8)(18)1	⊡	—	12	3.607$_8$	—	2.551$_1$	—	2.551
47 Silver	(2)(8)(18)(18)1	⊡	—	12	4.077$_8$	—	2.883$_5$	—	2.883
79 Gold	(2)(8)(18)(32)(18)1	⊡	—	12	4.069$_9$	—	2.877$_8$	—	2.877
Group IIA in Periodic Sequence									
4 Beryllium	(2)2	⬡	1.584$_8$	6,6	2.267$_9$	3.594$_2$	2.223$_5$	2.267$_9$	2.25
12 Magnesium	(2)(8)2	⬡	1.6236	6,6	3.202$_2$	5.199$_1$	3.190$_0$	3.202$_2$	3.20
20 Calcium	(2)(8)(8)2	α=⊡	—	12	5.56	—	3.93	—	3.93
(data for 450°C.) →		β=⬡	1.640	6,6	3.94	6.46	3.94	3.955	3.98
38 Strontium	(2)(8)(18)(8)2	⊡	—	12	6.07$_5$	—	4.29$_6$	—	4.29$_6$
56 Barium	(2)(8)(18)(18)(8)2	⊞	—	8	5.01$_5$	—	4.34$_3$	—	4.48
88 Radium	(2)(8)(18)(32)(18)(8)2	—	—	—	—	—	—	—	—
Group IIB									
30 Zinc	(2)(8)(18)2	⬡	1.856$_0$	6,6	2.659$_0$	4.935$_1$	2.659$_0$	2.906$_1$	2.748
48 Cadmium	(2)(8)(18)(18)2	⬡	1.885$_2$	6,6	2.973$_6$	5.606$_9$	2.973$_6$	3.287$_2$	3.042
80 Mercury	(2)(8)(18)(32)(18)2	▱	α=70°31.7'	6	2.999 ← at -46°C.		2.999	—	3.10
Group IIIA in Periodic Sequence									
5 Boron	(2)3	—	—	—	—	—	—	—	2.80 to 2.86 (note b)
13 Aluminum	(2)(8)3	⊡	—	12	4.041$_4$	—	2.856$_8$	←	
21 Scandium	(2)(8)(9)2	—	—	—	—	—	—	—	
39 Yttrium	(2)(8)(18)(9)2	⬡	1.588	6,6	3.663	5.814	3.595	3.663	3.629
57 Lanthanum	(2)(8)(18)(18)(9)2	α=⬡	1.613	6,6	3.754	6.063	3.727	3.754	3.741
		β=⊡		12	5.296		3.754		3.745
89 Actinium	(2)(8)(18)(32)(18)(9)2	—	—	—	—	—	—	—	—
Group IIIB									
31 Gallium	(2)(8)(18)3	▯	—	—	4.5167	7.6448	(note c)	—	—
		a÷b÷c=1:0.99868:1.69257			b=4.5107				
49 Indium	(2)(8)(18)(18)3	◬	1.077	4,8	4.583	4.936	4 at 3.241	8 at 3.368	3.138
81 Thallium	(2)(8)(18)(32)(18)3	α=⬡	1.600	6,6	3.450	5.520	3.404	3.450	3.427
		β=⊡	—	12	4.841	—	3.423	—	3.423

Notes: (a) ⊞ is body-centered cubic; ⊡ is face-centered cubic; ⬡ is close packed hexagonal; ▱ is simple rhombohedral; ▯ is orthorhombic; ◬ is face-centered tetragonal

(b) Appears to be smaller in some alloys

(c) 8 atoms to unit cell; each atom has 1 neighbor at 2.437, 2 at 2.706, 2 at 2.736 and 2 at 2.795

Careful tests, however, indicate a saving of at least 10% of the fuel in the openhearth furnace, with resultant advantages of higher production, lessened repairs and closer compliance with specifications as to composition and quality of product.

Automatic control of the openhearth furnace includes: (a) Control of supply or consumption of fuel, either at one definite rate, or at a rate which varies in accordance with the desired temperature of the roof or other important point or region; (b) regulation of furnace pressure; (c) control of shape, size and position of flame; (d) regulation of air supply in relation to fuel, so as to produce a definitely varying volume of products of combustion; (e) regulation of proportions of liquid or gaseous fuels — or both, where two or more fuels are used in combination; (f) regulation of flow of exit gases to distribute the heat among the regenerators; (g) regulation of interval between reversals in accordance with indications of differential temperature between incoming and outgoing regenerators.

Automatic control of furnace conditions begins with regulating the rate of fuel supply in accordance with one or more temperature indications, among which that of the furnace roof is the determining measurement, to prevent dripping roofs while permitting operation at the highest safe temperature continuously.

Regulation of furnace pressure is in reality the control of the flow of outgoing gases at a rate which corresponds exactly with their formation. This regulation, in order to be useful, should be as accurate as possible, since small variations in pressure produce considerable change in flow. Accurate regulation of furnace pressure prevents infiltration of cold air, and at the same time maintains a constant shape and size of flame, promoting continuous heat transfer and avoiding unnecessary wear on the furnace walls and ends.

Control of shape and size of flame is effected by the size and shape of gas port, where gaseous fuels are used, and by the use of a regulated burner where all or part of the fuel is liquid. Such fuels are atomized by steam, and automatic control of the oil-steam ratio in a correctly designed burner regulates the size, shape and position of the flame.

Air supply is most simply and reliably governed by regulating the ratio between fuel and combustion air. In the openhearth process, means must be provided for varying the ratio at successive stages of refining. This may be done manually, or automatically in accordance with the oxygen content of the products of combustion. Requirements as to length and shape of flame preclude the possibility of instantaneous combination of fuel and air; gas and air ports are so shaped that the air meets the outside of a gas stream, so that the length and shape of flame, as well as its temperature, depend on other factors than the amount of excess air. Moreover, such excess has the bad effect of increasing the volume of products of combustion, increasing the carryover of slag and dust particles to the regenerators, decreasing the efficiency of the latter, and for these and other reasons adding to the fuel requirement and increasing the cost of repairs.

Many openhearths are fired by a mixture of fuels. These may be blast furnace gas and coke oven gas; coke oven gas and tar; coke oven gas and oil; blast furnace gas, coke oven gas and liquid fuel or blast furnace gas; coke oven gas and producer gas. Other combinations are used sometimes for the sake of efficiency and sometimes by reason of availability. Where combinations are used, the regulating system should produce the following effects, and devices for so doing are now available:

1. Maintain a constant heat input to the furnace by automatically replacing one fuel by another in the event of a shortage of the first.
2. Permit regulation, through one adjustment, of the total heat input.
3. Totalize the air required for combustion of all the fuels and regulate a single air fan so as to provide the correct supply, maintaining the correctness of the air supply in case of variation in fuel supply.

The shape of gas and air ports is usually designed with reference to conditions during the phase of the process when the port acts as a burner and not as an outlet. Invariably the tendency at the outgoing end is to put too much gas through the air checkers. This may be avoided in some degree by varying the construction, but for complete adjustment it depends on regulation of dampers in the outlets of the two checker chambers. The instrumental indications utilized for this purpose are those of comparative temperatures in the regenerator flues.

"Automatic reversal" is not "automatic regulation" in the sense in which it has been used in describing continuously maintained conditions. It is rather a determination of time for the reversing operation in accordance with an instrumental indication of temperature or of differential temperature. The method utilizing temperature differences in the checkers permits each reversal to be determined by the furnace itself.

Heating Furnace Control

Control of a heating furnace includes (a) regulation of temperature, (b) adjustment of atmosphere within the furnace with respect to its content of combustible gases or oxygen, and (c) governing the shape and position of the flame. In regenerative furnaces it may also be desirable to regulate one or more of the above-mentioned conditions pertaining to the openhearth refining furnace.

Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys" Monograph No. 1, British Institute of Metals

Element Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (note a)	Axial Ratio c ÷ a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter (Coordination No. 12)
Group IVA in Periodic Sequence									
22 Titanium	(2)(8)(10)2	⬡	1.601	6,6	2.953	4.729	2.915	2.953	2.93
40 Zirconium	(2)(8)(18)(10)2	α=⬡	1.589	6,6	3.223	5.123	3.166	3.223	3.19
(data for 867°C.)		β=⧈	—	8	3.61	—	3.126	—	—
72 Hafnium	(2)(8)(18)(32)(10)(2)	⬡	1.587	6,6	3.200	5.057	3.139	3.200	3.17
90 Thorium	(2)(8)(18)(32)(18)(10)(2)	⊡	—	12	5.077 or 5.091	—	3.590 or 3.600	—	—
Group IVB, Including Carbon and Silicon									
6 Carbon, diamond	(2)4	◇	—	4	3.5606	—	1.5113	—	—
graphite	—	⬡ (b)	2.75	6	2.46	6.78	1.42	2.46	—
14 Silicon	(2)(8)4	◇	—	4	5.418	—	2.346	—	—
32 Germanium	(2)(8)(18)4	◇	—	4	5.647	—	2.445	—	2.788
50 Tin, gray	(2)(8)(18)(18)4	◇	—	4	6.46	—	2.797	—	3.164
white	—	△	0.5456	4,2	5.8194	3.1753	3.0161	3.1753	—
82 Lead	(2)(8)(18)(32)(18)4	⊡	—	12	4.9389	—	3.4923	—	3.494
Group VA in Periodic Sequence									
23 Vanadium	(2)(8)(11)2	⧈	—	8	3.033	—	2.627	—	2.69
41 Columbium	(2)(8)(18)(12)1	⧈	—	8	3.294 ±0.001	—	2.853	—	2.94
73 Tantalum	(2)(8)(18)(32)(11)2	⧈	—	8	3.298 ±0.002	—	2.854	—	2.94
91 Protoactinium	(2)(8)(18)(32)(18)(11)2		—	—	—	—	—	—	—
Group VB									
7 Nitrogen	(2)5	α=cubic	—	—	5.66	—	1.06	—	—
15 Phosphorus	(2)(8)5	□	α=34° 7′	3,3	5.14	—	1.74	3.01	—
33 Arsenic	(2)(8)(18)5	□	α=53°49′	3,3	4.151	—	2.5086	3.1465	—
51 Antimony	(2)(8)(18)(18)5	□	α=57° 5′	3,3	4.497	—	2.879	3.378	3.228
83 Bismuth	(2)(8)(18)(32)(18)5	□	α=57°16′	3,3	4.7365	—	3.105	3.474	3.64
Group VIA in Periodic Sequence									
24 Chromium	(2)(8)(13)1	α=⧈	—	8	2.8786	—	2.4929	—	2.57
		β=⬡	1.626	6,6	2.717	4.418	2.709	2.717	2.71
42 Molybdenum	(2)(8)(18)(13)1	⧈	—	8	3.1403	—	2.7196	—	2.80
74 Tungsten	(2)(8)(18)(32)(12)2	α=⧈	—	8	3.1583	—	2.7352	—	2.82
		β, (c)	8 atoms in unit cell →		5.038		2.519	2.816	
92 Uranium	(2)(8)(18)(32)(18)(12)2	Mono-clinic	a:b:c=1:1.73:1.17 β=64°18′		2.829	3.308	2.829 ← Note d		—
					b=4.887				
Group VIB									
8 Oxygen	(2)6	—	—	—	—	—	—	—	—
16 Sulphur	(2)(8)6	□ (d)	2.315	—	10.61	24.56	—	—	—
34 Selenium	(2)(8)(18)6	⬡ (e)	1.140	2,4	4.337	4.945	2.316	3.457	—
52 Tellurium	(2)(8)(18)(18)6	⬡ (e)	1.33	2,4	4.445	5.912	2.858	3.46	—
84 Polonium	(2)(8)(18)(32)(18)6	—	—	—	—	—	—	—	—

Notes: (a) ⧈ is body-centered cubic; ⊡ is face-centered cubic; ⬡ is close packed hexagonal except as noted; ◇ is diamond; △ is tetragonal; □ is rhombohedral and □ is orthorhombic

(b) Graphite is hexagonal, not close packed, with four atoms per unit cell.

(c) Cubic structure; two positions distinguishable, X and Y. Each atom X has 12 Y at 2.816 Å; each atom Y has 2 Y at 2.519 and 4 X at 2.816 Å

(d) 128 atoms in unit cell. Data from International Critical Tables or A.S.M. Metals Handbook

(e) Hexagonal, not close packed; each atom has 2 neighbors at d_1 and 4 at d_2

The heating furnace differs not only in details of these control problems but also in the desirability of maintaining an atmosphere in which scaling will be minimized. This atmosphere may be maintained by regulating the fuel-air ratio, checked either by intermittent or continuous analyses, or controlled automatically from an indication of the combustible content in the flue gases. An oxygen or CO_2 indication may also be used for this purpose. The most recent method employs the thermal-conductivity principle for measuring and automatically controlling "quality" of atmosphere with a zero-center instrument. The results of atmosphere control are among the most important in the entire field of automatic regulation.

Testing Instruments

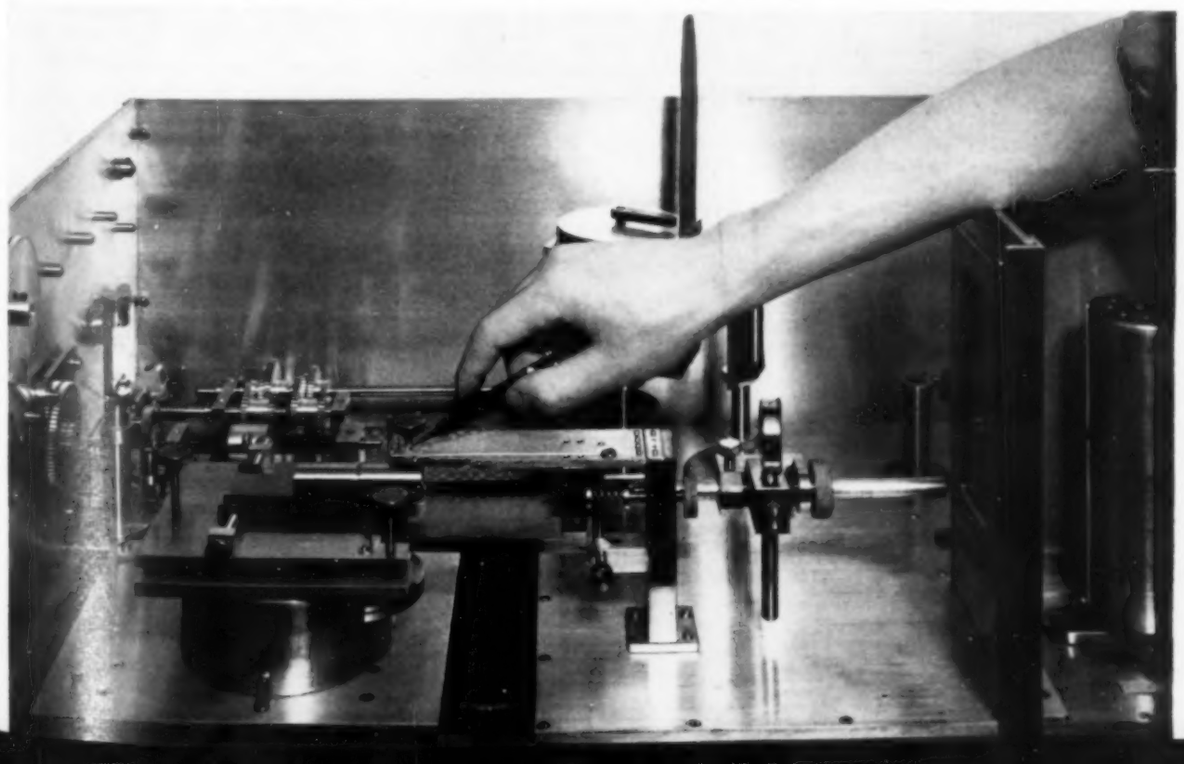
To many ⊜ members, "industrial" instruments comprise not only the **plant** instruments but a few classes of laboratory apparatus, particularly the devices for performing standardized physical tests, and for aiding human vision in observing microstructural characteristics. Many readers could point to the glorious histories of several types of equipment in their physical testing and metallographic laboratories. Perfectly true! But you all have already read numerous articles on early testing machines, early microscopes, early cameras and early spectroscopes. Moreover, you have easy access to these historical treatments in your magazine files and on your bookshelves. The authors' duty to you, in dealing with these categories of devices, is to discuss recent developments and future probabilities.

The tensile testing machine, as a type, affords an excellent example around which our discussion can be built. Galileo three hundred years ago and van Musschenbroeck two hundred years ago built its precursors; Perronnet, Gauthey, Soufflot and Rondelet built its real prototypes about a century and a half ago; then . . . nothing really new until modern times, for this galaxy of Frenchmen had built machines which could be **refined** but never **improved** until metallurgists required more than merely a single set of three measurements (load, elongation and reduction of area). Decades of intelligent interpretation of results, decades of painstaking study of testing conditions in minute details, decades of correlation of several arts and sciences, decades of teamwork between metallurgists and designers — these suddenly blossomed into the machines wherein all important conditions, **including time elements**, are exactly controlled, and wherein results take the form of automatic integrations and autographic records. Let us be specific and try to describe "The Ideal Tensile Testing Machine."

1. First of all, this ideal machine has been carefully designed to impress a pure tension upon the specimen in exact alignment with its axis. Unless this condition of correct alignment of stress prevails, a **tensile** test is practically useless. The means by which this alignment is secured must be robust and permanent so as to withstand repeated and forcible shocks.

2. The devices provided for gripping the specimen are carefully designed and built to assure a uniform distribution of stress throughout the cross sectional area of the specimen. We must remember that the interpretation of tensile tests depends entirely upon two premises — that the stress applied is in exact alignment with the axis of the specimen, and that the stress is uniform throughout its cross section. If these two statements be not true the test is worthless.

Profilograph, for Measuring the Smoothness of Finish on Highly Machined or Polished Surfaces. Pencil points to a tiny mirror mounted on a diamond point which is traversed over the surface being studied, and its irregularities are magnified optically and recorded on a photographic plate under the inspector's arm



Crystallography of the Chemical Elements

As Tabulated by William Hume-Rothery
in "The Structure of Metals and Alloys" Monograph No. 1, British Institute of Metals

Element Atomic No.	Electron Arrangement in Free Atoms	Crystal Structure (note a)	Axial Ratio c ÷ a	Coordination No.	Lattice Constant a	Lattice Constant c	Interatomic Distance d_1	Interatomic Distance d_2	Atomic Diameter (Coordination No. 12)
Group VII A in Periodic Sequence									
25 Manganese	(2)(8)(13)2	α = Cubic (note b) β = Cubic (note c)	—	— 12	8.894 6.300	—	—	—	—
43 Masurium	(2)(8)(18)(14)1	—	—	—	—	—	—	—	—
75 Rhenium	(2)(8)(18)(32)(13)2	⬡	1.6148		2.7553	4.4493	2.7349	2.7553	2.75
Group VII B									
9 Fluorine	(2)7	—	—	—	—	—	—	—	—
17 Chlorine	(2)(8)7	—	—	—	—	—	—	—	—
35 Bromine	(2)(8)(18)7	—	—	—	—	—	—	—	—
53 Iodine	(2)(8)(18)(18)7	▯	a÷b÷c = 1÷1.51÷2.04		4.795 b = 7.255	9.780	2.70	(note d)	—
85 Alabamine	(2)(8)(18)(32)(18)7	—	—	—	—	—	—	—	—
Group VIII in Periodic Sequence									
26 Iron	(2)(8)(14)2	α = ⧈ γ = ⊡	—	—	2.861o 3.64 ← at 900°C.	—	2.477 2.580	—	— 2.52
27 Cobalt	(2)(8)(15)2	α = ⬡ β = ⊡	1.624	— —	2.507 3.545	4.072	2.499 2.507	2.507	2.50 2.507
28 Nickel	(2)(8)(16)2	α = ⬡ β = ⊡	1.64	— —	2.49 3.517o	4.08	2.49 2.486	2.49	2.49 2.487
44 Ruthenium	(2)(8)(18)(15)1	⬡	1.585	—	2.695	4.273	2.643	2.695	2.67
45 Rhodium	(2)(8)(18)(16)1	⊡	—	—	3.795	—	2.683	—	2.684
46 Palladium	(2)(8)(18)(18)-	⊡	—	—	3.882	—	2.745	—	2.745
76 Osmium	(2)(8)(18)(32)(14)2	⬡	1.578	—	2.730	4.309	2.669	2.730	2.70
77 Iridium	(2)(8)(18)(32)(15)2	⊡	—	—	3.831	—	2.709	—	2.709
78 Platinum	(2)(8)(18)(32)(16)2	⊡	—	—	3.915	—	2.768	—	2.769
Rare Earth Group									
58 Cerium	(2)(8)(18)(19)(9)2	α = ⬡ β = ⊡	1.62 —	6,6 12	3.65 5.143	5.91	3.63 3.637	3.65	3.64 3.637
59 Praseodymium	(2)(8)(18)(20)(9)2	⬡	1.620	6,6	3.657	5.924	3.636	3.657	3.65
60 Neodymium	(2)(8)(18)(21)(9)2	⬡	1.608	6,6	3.657	5.88	3.619	3.657	3.64
68 Erbium	(2)(8)(18)(29)(9)2	⬡	1.63	6,6	3.74	6.09	3.73	3.74	3.73

Notes: (a) ⧈ is body-centered cubic; ⊡ is face-centered cubic; ⬡ is close-packed hexagonal; ▯ is orthorhombic

(b) Approximates ⧈ where each lattice point is a cluster of 29 atoms; 1 type X, 4 type A, 12 type D_2 and 12 type D_1. The X atoms occupy the largest volume and the D_2 the smallest. Interatomic distances of neighboring atoms are as follows:

X atoms have 12 D_2 at 2.71
4 A at 2.82

A atoms have 1 X at 2.82
3 D_1 at 2.49 and 3 at 2.96
3 D_2 at 2.69 and 3 at 2.89

D_2 atoms have 1 X at 2.71
2 A at 2.69 and 1 at 2.89
1 D_2 at 2.24 and 2 at 2.38
1 D_1 at 2.45, 2 at 2.51 and 2 at 2.66

D_1 atoms have 1 A at 2.49 and 1 at 2.96
1 D_2 at 2.45, 2 at 2.51 and 2 at 2.66
6 D_1 at 2.67

(c) Complicated structure with 20 atoms of two kinds in unit cell.

Each atom of the first kind has
3 neighbors at 2.365
3 " " 2.530
3 " " 2.671
3 " " 2.675

Each atom of the second kind has
2 neighbors at 2.530
2 " " 2.615
4 " " 2.659
2 " " 2.671
2 " " 2.675

(d) Atoms arranged in pairs so that each one has one close neighbor at 2.70. Data from A.S.M. Metals Handbook.

3. This ideal machine is provided with an accurate, automatic indication of the load which is being applied; accuracy within $\pm 1/4\%$ is guaranteed and is attained partly by reason of the fact that its designer has not tried to make it operate over too great a range of loads. For most purposes it is a mistake to attempt to build a machine that will be required to measure accurately loads of less than 10% of its capacity.

4. Machines which require manual balancing of the load introduce the personal equation of the operator at a vital point where it should be excluded; therefore the ideal machine is automatically balanced regardless of whether the load is increasing or decreasing and it makes an accurate stress-strain diagram which permits the determination of yield points by the newer and more accurate methods. The "drop of the beam" method of determining yield points, which is now generally used, is satisfactory on only a few classes of materials and gives wholly unreliable results on many. This method of determining yield points is a continual source of worry to the operator and of inaccuracy in the results. On the other hand, some accurate extensometers are slow and tedious to use, and frequently impossible in routine testing.

Permanent Calibration

5. The calibration of this machine is permanently accurate because of the correct design of its parts, built to withstand the severe shocks incident to its use.

6. The speed with which the specimens may be pulled is adjustable and under the control of the operator at all times. But a step beyond this provision has been taken: The speed is maintained automatically at a constant value, set by the operator, and is indicated on a dial visible to him. Controversies arising between different testing laboratories regarding tensile properties can frequently be traced to the fact that different and uncontrolled speeds of pulling the tests are used.

7. All exposed metal parts are of an alloy steel that resists corrosion and maintains permanently the fine appearance it had on the test floor.

8. Controls and dials for the use of the operator are within easy reach and the specimen grips are arranged so that a test piece can be inserted in the machine with a minimum of effort. Charts for the autographic stress-strain diagrams are continuous like those now used on recording electrical instruments and, being approximately 90 ft. long, require replacement only at long intervals.

In most respects "the ideal tensile testing machine" is available today — and in an interesting variety of forms obtainable from several American and foreign manufacturers.

Improvements and refinements observable in the evolution of other testing machines may be said to be parallel but not similar. The biological analogy — evolution — suggests itself because a striking trend of the present decade is the "origin of species," as new tests are proposed, debated, and adopted. Sometimes the origin is a slightly different purpose which seemingly calls for a correspondingly slight modification of a tester; in other instances a new purpose is conceived as a new and distinct property of matter is isolated, and the novel method calls for a radical departure from previous designs. Even a single "property of matter" may receive so many new definitions that multiplication continues to be the trend. We do not refer so much to the broad territory of hardness (which has long since been split up into distinct properties) as to each of the fields within this territory.

A familiar example is the "indentation hardness" field of research and of routine tests, in which there probably are a dozen different tests, most of them based on slightly different definitions rather than on essentially different methods. Maybe it will be fifteen by the time this is printed; maybe it already is twenty by reason of proposals recently made before Swiss or Soviet or Swedish societies and not yet seen by the authors. No sarcasm is implied; if any group of serious workers adopt a definition for their own use, they have the right to do it, and the data which they accumulate may not only interest other workers but prove to be an influence toward eventual reduction of definitions for indentation hardness into an irreducible number of variants, each quantitative, each significant and each beautifully suited to a group of industries or to a branch of research.

The authors advocate this line of approach in all fields of hardness testing, but with the proviso that correlation be ever kept in mind, so that the fabricating industries can completely specify a comprehensive set of hardness properties by means of a set of names (or letters) and numbers. Imaginary example: "X — 53 to 55, Y — 700 to 750, Z — 29 to 31" where X would represent the result of a magnetic test, Y the result of an impact test, and Z the result of a test affecting the surface without being influenced by the thickness.

Relationships between mechanical properties and the results of tests of such properties as permeability, core loss or coercivity are increasingly recognized by ferrous metallurgists and manufacturers. Both the ferrous and non-ferrous industries are witnessing a similar acceptance of X-rays, electron diffraction and spectroscopy as testing equipment. In consequence, the classes and types of physical testing machines, apparatus and instruments will go right on multiplying by reason of advances in science, chiefly in substituting non-destructive exploratory methods for the older, more direct determinations.

Advances in Optical Equipment

Not so many years ago, if a visitor in the physical testing department of a steel or brass company's laboratory dared to utter such expressions as cathode-rays or electron diffraction, he would have incurred suspicion. Today, not only are the industrial research workers running a close race with their erstwhile teachers, the pure scientists, in the development of non-destructive testing methods, but the production men are beginning to wonder whether it would not be well to move various testing instruments from the laboratory to the plant and call them inspection machines.

This trend will be discussed by itself at the end of this article, but it will require our walking from the laboratory to the plant inspection departments and we can't leave the laboratory without stepping into the spectrographic and metallographic rooms.

In spectrometry and spectrography there is a decided trend — following the history of physical testing technique — toward minimizing any

Measuring and Recording the Temperature of Metal as It Passes Through the Rolling Mill Requires Automatic Action Within ½ Sec. or Less. Photo of sighting element, courtesy Minneapolis-Honeywell Co.

dependence on skill and judgment by introducing quantitative methods and automatic instruments. Recent developments and refinements in wedge sectors and in densitometers (and in emulsions and developing solutions which are the prerequisites) afford excellent examples. Such innovations are a blessing to highly trained specialists who are thereby spared many tedious hours — and they are of economic value in permitting more creative work without boosting the budget. But skill in qualitative analysis must of course continue to be called for. After all, developments in instrumentation will never rob us of the thrill of seeing an experienced analyst take a quick glance at a film and declare "Too much lead!"

The "ideal metallographic equipment" had not only been specified at least ten years ago, but refinements reached such a degree of perfection before 1937 that there is no discernible trend as far as the instrument makers are concerned. There is a decided trend, however, in the growing acceptance by industrial bigwigs of metallography's usefulness. Loosening of purse strings has had the happy consequence that certain highly refined equipments previously built to order are now carried in stock for immediate delivery. Highly perfected illuminators and oil-immersion objectives no longer are a source of hopeless envy, for they are O.K.'d on the requisitions.

Upon the correct preparation of samples depends the quality of the micrographs. Recent improvements in polishing methods and apparatus make the surface of a specimen sufficiently flat for simultaneous sharp focus of all components in the field of high-power microscopes. In consequence the numerical connotation of "high-power" has greatly increased. Another improvement in the results is the complete absence of relief at grain boundaries when the components are of different hardness. Advances in the technique of mounting specimens in plastics have been made rapidly, thanks to teamwork by the groups concerned.

Automatic Inspection Departments

Up to now we have used few superlatives, but now we drop all restraint. Without hestitation or mental reservation we predict that the most interesting, the most far-reaching, the most numerous, the most money-saving and the most civilizing applications of modern instrumentation during the next five or ten years will consist of converting inspection and testing operations now depending on human eyes and human memory (and in too many cases on human judgments) into automatic routines. We are compelled to say "five or ten years" because we don't know what changes America's politico-economic structure will undergo. If the latter continues to change gradually, the trend toward automatic inspection and testing will follow the curve of natural growth (slow-fast-slow) which it is just entering. In the event of war or other cataclysm, this progress will depend on the extent to which industrial mobilization will aim to conserve human energy, and the curve may take an unnatural form. In any event it will go away up within a decade or so.

Glimpses into the background of this dawning development have been given above, in allusions

to the yesterday's scientific laboratory curiosity becoming today's research instrument and tomorrow's plant instrument. A more specific and almost sensationally dramatic example will now be given which is close to ⊜ members.

Up to 1922, it was believed that all defective casehardening was due to incorrect practice in the forming, carburizing and hardening operations; all chemical tests, microscopic examinations and other methods then in vogue gave no indication whereby one could tell whether a certain furnace charge, or ingot, or bloom, or bar, or billet, would or would not carburize properly.

In 1922 McQuaid and Ehn published their important discovery "that the structure of the case both before and after quenching is greatly affected by the actual condition of the steel itself as made . . . Work from good batches hardens properly whereas the other work will not harden" when subjected to identical forming and heat treating operations. They proposed a standard procedure, involving a definite carburizing treatment followed by a microscopic examination of carburized samples. This test procedure has remained practically unaltered as the only accepted standard for determining whether the steel in a given ingot is normal or abnormal steel. See your ⊜ **Metals Handbook**, pages 580 to 583. Until recently there was no test whereby a quantitative determination could be made and the result expressed as a number. All proposed methods of determining whether a given specimen is "normal" or "abnormal" included visual examinations.

There was needed a fully automatic apparatus which would subject a small sample to a standardized and reproducible heat treatment, indicate its degree of abnormality on a numerical scale, and do it quickly.

Solution of the problem was sought along the line of a magnetic test, as offering the best basis for a measuring instrument — one that would give quantitative readings. It was discovered that the relation between "degree of abnormality" and a magnetic effect readable on the scale of an electrical instrument manifested itself on heating the specimen to a critical temperature inversely proportional to the magnetization; without, however, reaching the critical temperature at which structural changes occur in ferrous alloys. This suggested a device in the form of a combination coil for simultaneously magnetizing and heating the sample and dictated the form that the samples should take, namely a round bar.

Since the most indicative readings were obtained by using an electrical ratio instrument with a standard sample in one coil and the test sample in another, further development consisted in ascertaining the optimum physical dimensions and electrical constants of a two-coil type of inspection instrument and determining the optimum heating period. A period of 80 sec. for heating the sample was found to give the most sensitive results. The standard sample (which forms a part of the circuit and apparatus) and the individual test samples (each representing a heat under study) are miniature test ingots forged down to ⅜ in. diameter by 9½ in. long; surface cleaned of loose scale; straightened if necessary for easy insertion.

Twenty-Five Measurements, Some to Within ± 0.00025 In., Made on Each Camshaft as It Passes Through This Inspection Machine. Photo courtesy Ford Motor Co.

On theoretical grounds the objection might be raised that a differential magnetic measurement, read on a commercial voltmeter, is not a reading of the microstructure of abnormal steel. But abnormality — as far as the practical worker is concerned — is neither a peculiar microstructure nor a peculiar diffraction spectrum. It is "that property of a steel which affects its suitability for casehardening" and nothing else. The thermomagnetic test is said to be a true measure of that property — of the degree of abnormality. Its results check with McQuaid-Ehn test determinations.

There are already in practical use several magnetic methods of continuous inspection — none as dramatic, perhaps, as the direct-reading method of measuring "abnormality" on a "good-bad" scale like a radio tube, but similar thereto in that they measure various properties, or determine the presence of flaws. *(Continued on page 500)*

Exposure Chart for Radiography of Steel

By Herbert R. Isenburger

St. John X-Ray Service, Inc., Long Island City, N. Y.

THESE DIAGRAMS for estimating the correct exposure time for the industrial radiography of steel are intended to supersede those published in **Transactions** ⊖, Vol. 23, p. 614, 1935, and are based on the following combination: Pulsating direct current tension generating equipment; line focus, grid action X-ray tube; high speed industrial intensifying screens; blue base safety film; 5 min. development at 65° F.; film density 0.7.

As an example for the correct use of charts and table, a solution is shown of this problem: "Find the correct exposure on 17-in. film at 36-in. focus-film distance for 3-in. boiler plate of density 7.85 using 220,000 volts and 8 milliamperes."

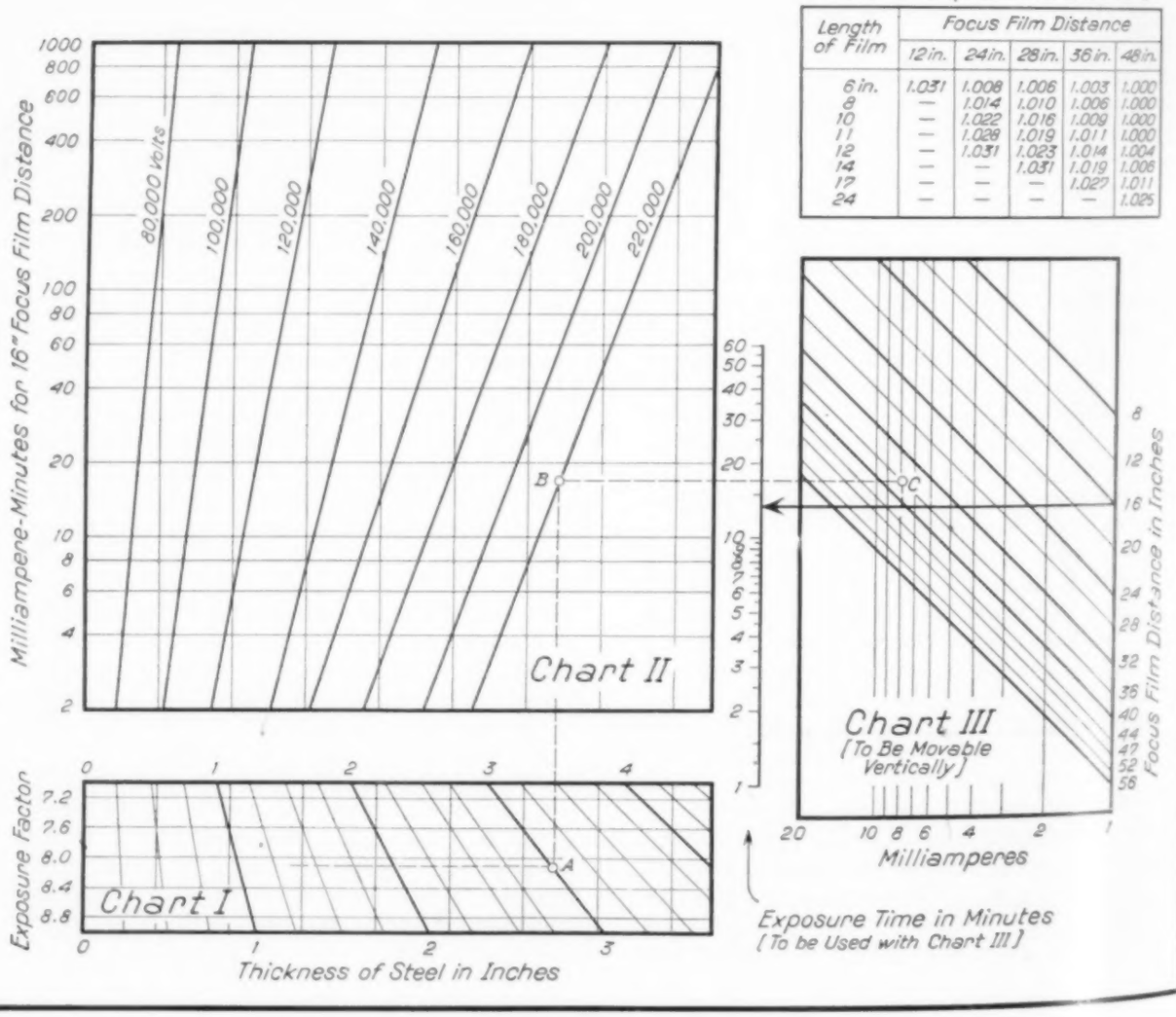
To compute the exposure factor at the ends of films of various lengths and at different focus-film distances, the factors shown in the table are multiplied by the actual density of the steel. In this example the factor 1.027 is located in the column for 36-in. focus-film in the line for 17-in. film. Multiply 1.027 by 7.85, the density of the steel to be radiographed, and the exposure factor is 8.1.

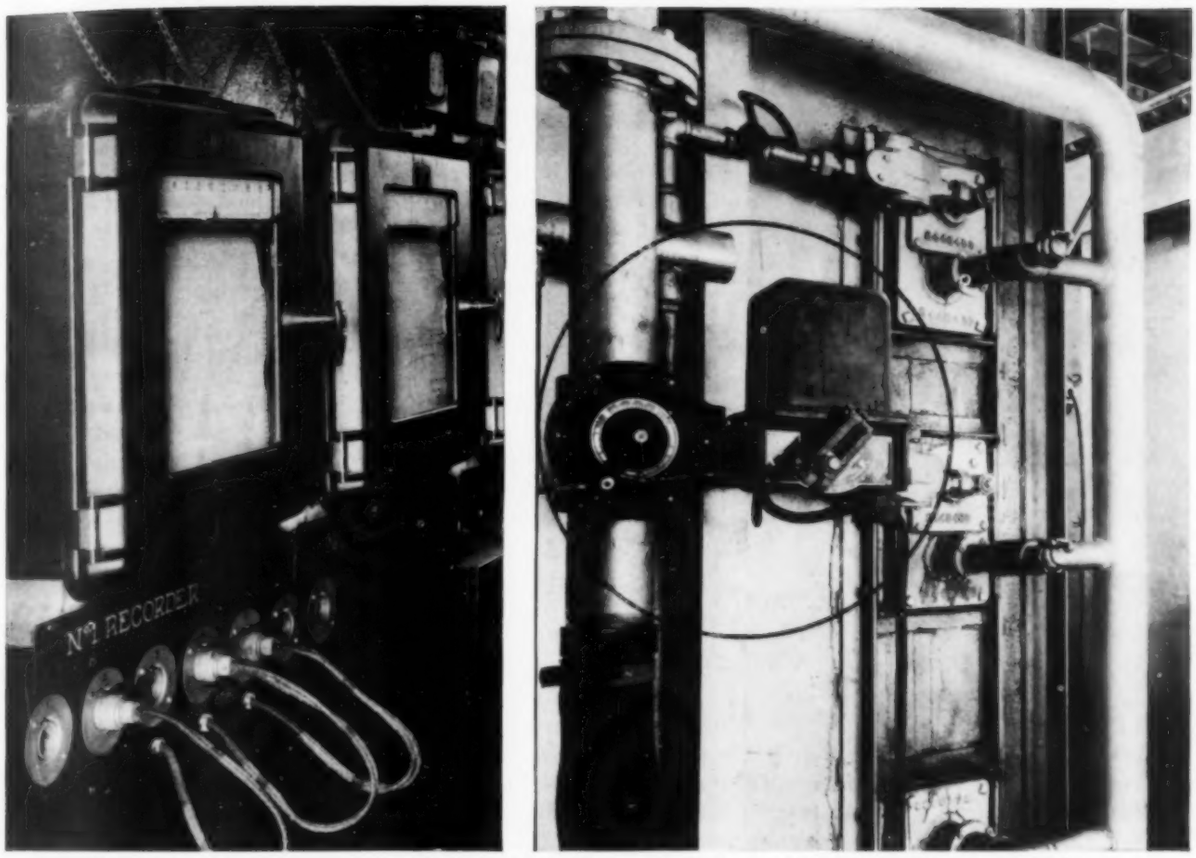
Find intersection of 8.1 with 3-in. line on Chart I (Point A), project upward to voltage of tube (Point B on 220,000-volt line in Chart II). Adjust Chart III so that Point C (corresponding to 36-in. focus-film distance and 8 milliamperes) is opposite Point B, and exposure time is read on central scale against arrow: 13½ min.

This time may be contrasted with 1 min. for the same thickness of steel of 7.6 density at 220,000 volts and 8 milliamperes but only 16-in. focus-film distance and 8-in. film.

Table of Exposure Factors

Length of Film	Focus Film Distance				
	12 in.	24 in.	28 in.	36 in.	48 in.
6 in.	1.031	1.008	1.006	1.003	1.000
8	—	1.014	1.010	1.006	1.000
10	—	1.022	1.016	1.009	1.000
11	—	1.028	1.019	1.011	1.000
12	—	1.031	1.023	1.014	1.004
14	—	—	1.031	1.019	1.008
17	—	—	—	1.027	1.011
24	—	—	—	—	1.025





Two principal units of Micromax Electric Control—At left, Micromax Controllers, with plugs for switching thermocouples to any desired furnace. At right, Drive Unit on a cover-furnace gas valve.

FOR *Any* FURNACE . . .

MICROMAX ELECTRIC CONTROL

With component parts exactly matching the Micromax Pyrometer in sensitivity and dependability, Micromax Electric Control makes available from couple to valve drive all the qualities that Micromax users associate with that Recorder. And—this Control fits any furnace, from blast furnace to small box-type unit. It can be standard for an entire plant—bringing big-furnace dependability to the regulation of small furnaces, and small-furnace simplicity to the big units.

At the Metal Show
See Micromax Instruments, Vapocarb-Hump & Homo Furnaces

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MEASURING INSTRUMENTS · TELEMETERS · AUTOMATIC CONTROLS · HEAT-TREATING FURNACES

JNA(5)

Methods utilizing magnetic effects are not the only ones! Electrostatics, electrodynamics, photo-electricity, piezo-electricity, thermo-electricity, thermionics, cathode rays — as well as our old friends hydraulics, pneumatics and of course mechanics — all are being conscripted into industry's service and given assignments on measuring instruments giving a continuous record and capable of being used by workers who never saw a physical laboratory. All branches of science and technology are contributing. Although automatic inspection is in its infancy, a book could be written about its successful applications.

These applications divide themselves into two distinct categories:

(1) Continuous gaging, measuring and other forms of inspection of materials such as wires or sheets, continuously passing through the measuring device.

(2) Part-by-part gaging, measuring or testing, nearly always with automatic selection and rejection, sometimes with automatic classification into a plurality of acceptable grades between the reject bins at both extremes.

Examples of the first category are rapidly being introduced in the metallurgical industries. Some rolling mills afford an insight into the future possibilities of (a) gaging or inspection at the point of production, which naturally suggests (b) automatic control of the certain magnitudes continuously measured. A believe-it-or-not application of a purely metallurgical nature is continuous automatic hardness control: As the strip (from which razor blades are made) leaves a continuous furnace it passes through a magnetic inspector which governs the heat treatment through servo-motors operating the fuel valve or electrical heating current.

Examples of the second category already abound in the mass production industries. From hundreds of applications one may cite, as an echo of the foregoing, the piston-pin hardness tester at the Ford Motor Co.; it is an automatic scleroscope wherein a small hammer rebounding from the pin intercepts a light beam for a certain interval if the hardness is correct, and a photo-electric relay causes the piece to advance along the "acceptable" line; if the pin is too hard, the hammer intercepts the light beam twice, and if the pin is not hard enough the hammer does not rebound high enough — in either case the relay trips a kick-out.

Among the advantages of subsituting automatic inspectors for human inspectors are not only the civilizing effect of reducing the sum total of human drudgery, spreading wider the material aids to civilization by reducing their costs, but even such prosaic matters as saving floor space. The Ford piston-pin hardness device just mentioned is one wherein five different inspections is assembled in one machine. Pins enter one end of the machine at the rate of 38 a min. and are conveyed along its length past five stations spaced 7½ in. apart, halting at each station for a particular inspection (like "physical exam day" in the Army). Station 1 tests automatically for surface smoothness by means of a carboloy-tipped feeler swung in the field of a magnet in such a manner that when roughness causes deflection beyond permissible extent, an amplified current trips a relay and the pin is ejected. Station 2 tests for scleroscopic hardness as above described. Station 3 tests for cylindricality by means of a U-shaped feeler which a taper of 0.0003 in. causes to deflect sufficiently to actuate a relay. In a somewhat similar manner Station 4 tests for concentricity by the three-point method. Station 5 measures diameter and its pointer controls a chute leading to one of five bins: Oversize rejects, +0.0001 in., ±0.00005 in., −0.0001 in., and undersize rejects.

Mentions have been made of measuring instruments, photo-electrically actuated. We cannot close without touching upon the metallurgical inspection possibilities of the cathode ray oscillograph. It is already being used for numerous determinations, some of them comparing a standard specimen with the test sample by the simultaneous deflection method, others obtaining directly the curves of hysteresis. It is just beginning to be used for automatic selection-and-rejection, one expedient consisting simply of pasting on the screen a narrow strip of opaque paper shaped like the diagram produced by an acceptable sample or finished product; if the product under test is sub-grade, the light-spot will show and a photocell will "see" it and a relay will be tripped.

Conclusion

What is there about modern industrial instruments that makes them so fascinating? What binds together so many ASM members with so many workers in so many non-metallurgical fields? Pyrometers, hardness testers, microscopes, CO_2 recorders and hot-blast controllers as such? No; more than instruments — Instrumentation.

That is to say, the combination of exact science and fine art, of practical experience and daring imagination, of specialized training and broad technical knowledge — all of which is involved in the successful application of industrial instruments. Breadth of technical knowledge is essential, for every innovation in one field is a borrowing from several others. Yes, and a touch of drama; the element of conflict, for every untried application met with obdurate Board-of-Directors' opposition in the past and every untried application will be opposed in the future. Which leads us to a final prophecy: This opposition will diminish by reason of the ever-increasing legislative regulation of industry. And if the government should let up in years to come, the advance of Instrumentation will go on just the same.

Foundry Work on High Chromium-Iron Castings

By John Sissener
Oslo, Norway

Fittings for Digestor and Sulphite Lines, for Paper Mill, Made of 24% Cr, 12% Ni Alloy by Sirver Steel Casting Co. Photo by Tetzlaff

IN 1933, the firm with which the author is connected entered upon the manufacture of corrosion resistant castings in its own foundry. A picture of our typical chromium castings is shown in the view on page 527. You will notice that these pieces are rather difficult castings, approximately 8 ft. in diameter, with a cross-section of ½ by 2½ in. They are used in machinery for handling dilute bleaching solutions in the pulp and paper industry.

Our furnace is photographed on page 525. It is of the Rennerfelt design you can read about in the early literature of electrometallurgy. It is now roofed with chrome-magnesite bricks ("Radex"), and the walls are of stamped dolomite. The roof is double, having an outer course of ordinary firebrick, 2½ in. thick.

At night the furnace gets cold; it is only working by day, and therefore we have to insulate it with movable asbestos cushions. This serves very well and when we turn on the current in the morning the furnace, after having been down for 16 hr., is still good and hot.

Two men are supposed to do all work at the furnace, including necessary repairs as well as charging and working the heat. The furnace never gives us any trouble and produces 1½ tons of chromium cast iron (30% Cr, 2.5% Ni, 0.70% C) in four hours. Two heats are thus made every working day.

Production is strictly of a jobbing foundry nature — everything is "tailor made," with a close eye on the cost sheet. Competition is keen among the foundries in Norway, but we were the first to take up this new line, since then making many hundreds of tons. Most of it has the following composition: Chromium 28 to 30%, nickel 2.5%, carbon 0.7%, silicon 0.7% max., molybdenum 0.3 to 1.0%, titanium or nitrogen as a grain refiner. It is my observation that castings of this sort are much more generally made in Europe than in America, an impression verified by remarks on "High Chromium Irons and Steels in Germany" by Prof. Eduard Maurer in a letter to METAL PROGRESS, May issue.

Chromium cast irons have the advantage of being cheaper than the 18% chromium, 8% nickel austenitic alloys, due to their lower alloy content. They have a high carbon content and

fluidity is good. Heat treatment of the product is not necessary.

The question is, "Is their corrosion resisting quality comparable to that of 18-8?" (It should be emphasized here that the straight chromium-irons are not regarded as a general substitute for 18-8, but merely are economical in certain well-defined uses, when first cost and annual charges are compared.) Attempts were made to determine this point of corrosion resistance in the laboratory, using solutions similar to those met by our castings in paper mill service — namely, dilute solutions of hydrochloric acid (1 to 2.5 g. per 1000 cc.) containing 0.06 to 0.09 g. of free chlorine. In six months 18-8 lost weight at the approximate rate of 50 g. per sq. meter per year, and is rated as unity. Compared to this particular alloy, all the others have the following resistance:

Stainless steel 18-8 was attacked at a rate	1
28% Cr, 2% Ni, 1% C, attacked twice as rapidly	2
Bronze	8
Brass	10
Very pure soft iron	30
Cast iron	200

Salt spray test for three months showed that chromium alloy was equal if not superior to 18-8. Water dip test showed similar results.

It has been suggested by some American friends that the excellence of Norwegian alloys in these respects is due to the purity of the iron used in the melt. They also point out that the corrosion resistance of the 18-8 type of material is greatly influenced by the other alloys it contains (as molybdenum) and its parentage and early history (manufacture and heat treatment). However that may be, the above figures are believed to represent first class products as now made in Norway.

We have also investigated heat resisting chromium-iron castings containing about 34% Cr and 1.5% C (and from what is to follow the reader will observe that it is a cast iron rather than a cast steel, when appraised from a mechanical viewpoint). Slow tensile tests were made of this and other high temperature alloys, as follows:

Alloy	At 930° F.	At 1650° F.
0.45% Carbon steel	38,000	
25 Cr, 20 Ni	58,000	18,000
21 Cr, 7 Ni	62,000	10,000
34 Cr, 1.5 C	52,000	6,000

We find, in our shop, the approximate values for machining stainless steels and cast irons as given in the tabulation.

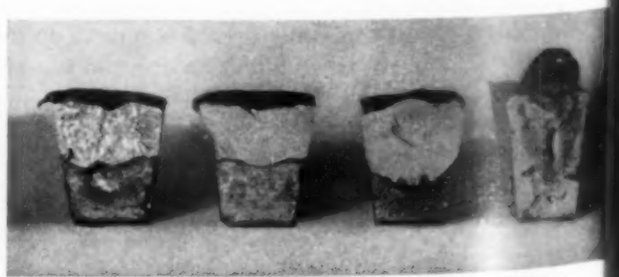
Machinability of High Chromium Castings

Cast Material	Rockwell Hardness	Cutting Speed, Ft. per Min.	
		Tungsten Carbide Tools	High Speed S
18 Cr, 8 Ni	C-15 to 17	90 to 105	30 to 4
27 Cr, 2.5 Ni, 0.25 C	C-20 to 25	75 to 90	24 to 3
27.5 Cr, 2.0 Ni, 0.75 C		60 to 75	24
Gray cast iron		450 to 540	80

A drawback which I think has been a great obstacle to the further development of the chromium cast irons is their coarse-grained microstructure. Through the addition of nitrogen, invented by the Electro Metallurgical Co. in America, the grain size is much refined, and thus the use of this valuable alloy will be extended. The present writer has worked with titanium; small additions greatly improve the structure, 0.04% being the perfect addition for 1% C, 30% Cr irons.

The table on the next page gives the results of some tests on typical heats containing titanium as a degasifier and grain refiner in variable amounts, but all below 0.10%. The bend test was made on a 1.18-in. round rod 24 in. long, loaded in the middle. Cast tensile test bars were 0.59 in. diameter. The photograph of fractures, just below, is also illuminating.

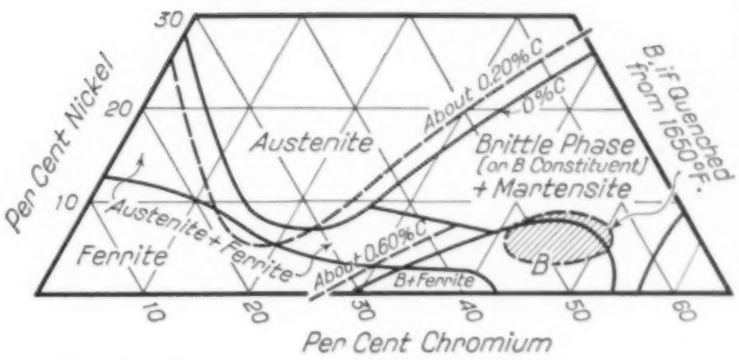
The author has found magnesium and aluminum a good gas scavenger for chromium cast irons. Magnesium provokes a violent reaction in the molten bath, and takes out gases. Afterwards the MgO reaction product is taken care of by phosphor copper in very small amounts. This "medicine" is frequently useful to get tight castings. Manganese and copper both increase the strength and the copper increases the resistance to dilute hydrochloric.



0.00 Ti 0.04 Ti 0.045 Ti 0.14 Ti

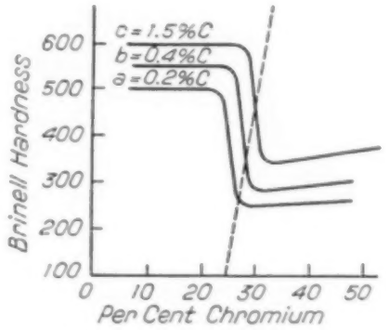
Test Ingots Containing Indicated Amounts of Titanium, Fractured to Show the Grain Size and Soundness

An important publication concerning chromium cast irons in Europe may be found in *Die Giesserei* for Sept. 11, 1936, from which is taken the attached constitutional diagram for iron, nickel and chromium. This, adapted from a diagram by Bain and Griffiths (*Transactions*, A.I.M.E., 1927, V. 75, p. 202) gives an excellent idea of how compositions must be controlled if the "brittle phase" and associated heat cracks are to be avoided. With usual carbons in castings and 2.5 to 4.0% nickel, the chromium should not be over 28%. Molybdenum up to 1.0% has a good influence in mitigating this brittleness (reducing brittle phase) when hot.



Phase Locations After Long Annealing in the Cr-Ni-Fe System. Full lines after Bain & Griffiths for very low carbon alloys. Dotted lines indicate influence of commercial carbon contents

The diagram alongside shows the relationship between chromium, carbon and hardness. This is also very important, for it is possible with its aid to obtain machinable castings with 1.5% carbon if you only keep your chromium high enough. 1.5% carbon will probably give you a Rockwell hardness above C-35 with 25% chromium. But if you increase the chromium to about 34% you will get machinable castings. These curves are all of alloys hardened in water from high temperature and you will see from these very clearly where the martensitic group stops, and the ferritic group commences.



Soft Castings Are Produced When Proper Balance Between Carbon and Chromium Is Attained. British patent 342295; R. Kuenhrich

It is also possible to obtain austenitic structure in these alloys if the nickel or manganese is high. Nickel is useful in adding strength to the alloy, but too much will render the high carbon, high chromium iron castings much less machinable.

Reference should also be made to the interesting work of Emmanuel Valenta in *Journal*, British Iron and Steel Institute, 1930.

Observations in American Foundries

With this background of information about conditions as they exist in Norway, a few words may now be in order on my observations on a recent inspection of several of the important foundries in America.

I found generally that chromium cast irons are comparatively little used in America. "Niresist" (high nickel — say 15% — with copper or chromium or both) has entered the field for mild corrosive liquids of a reducing nature, but high chromium cast iron ought to be equally good for other liquids of mild character. High chromium irons have also proven best for acid mine waters.

In America the 18-8 material with 3% molybdenum appears to be the favored material for sulphite liquids under pressure, although some pitting corrosion has been reported.

The 29-9-0.3 carbon is a good alloy for various acids and easier to handle in the foundry than the one just mentioned. But when high tensile strength at elevated temperature is

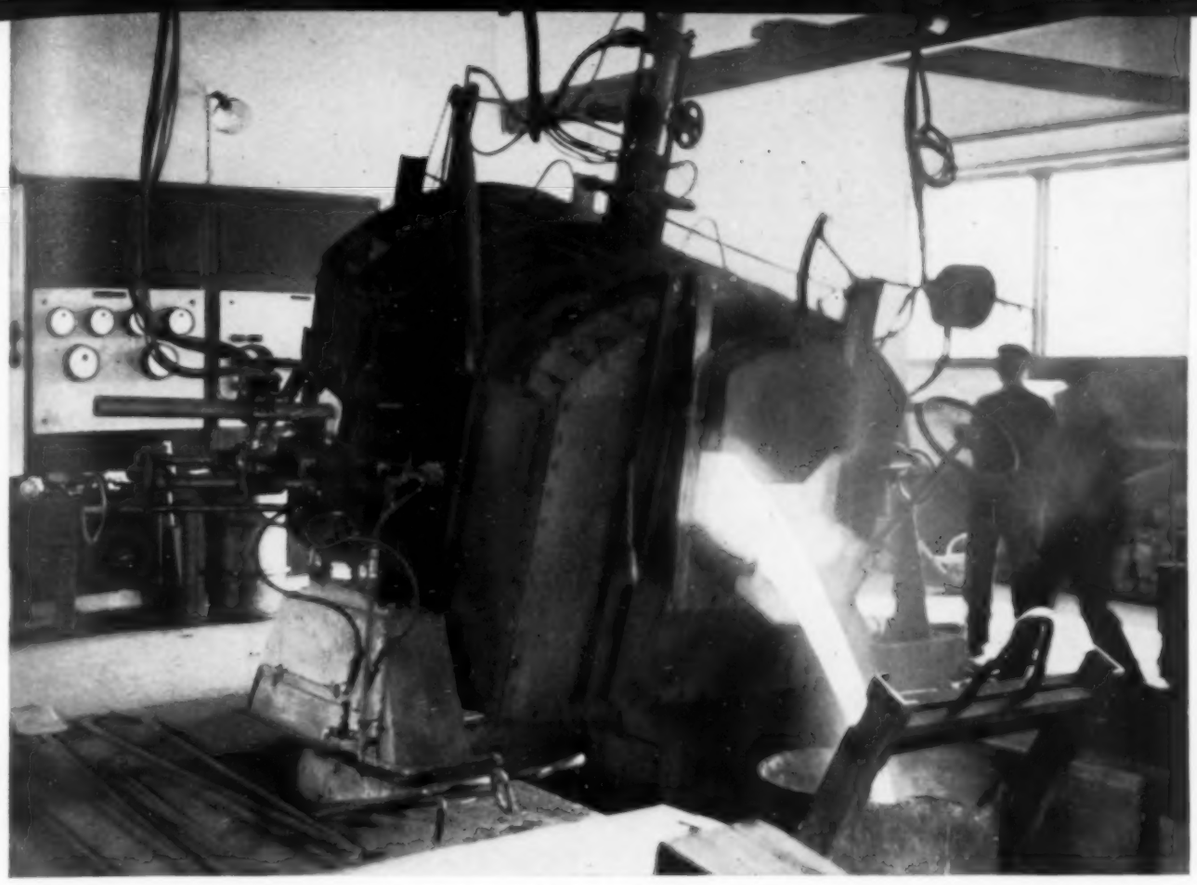
Physical Properties of High Chromium Cast Irons (With Titanium)

Approximate Analysis (<0.10% Ti)				Bend Test			Tensile Strength	Rockwell Hardness
C	Cr	Si	Ni	Total Load	Psi.	Deflection		
1.15	30.0	0.80	3.0	3500 lb.	13,800	0.8 in.		C-29.5
0.70	30.0	0.50	2.5	4150	16,300	0.87	60,500	C-29
0.80	30.0	0.65	3.2	4200	16,350	0.9		C-33
0.80	27.5	0.50	2.0	4300	16,600	1.12		C-32
0.75	31.0	0.64	2.5	3650	14,000	0.70	96,000	C-35

The A-B-C of Corrosion and Heat Resisting Steels

Arrangement due to F. R. Palmer. Adapted from The Book of Stainless Steels, Second Edition

Group A (Martensitic)	Group B (Ferritic)	Group C (Austenitic)
Chemical Analysis Chromium less than about 16%; carbon less than about 0.40%. May contain small percentages of tungsten, copper, nickel, silicon and more frequently molybdenum. Group is magnetic.	Chromium more than about 16%; carbon quite low, but can increase as chromium goes up. May contain small percentages of copper, nickel, silicon, molybdenum, tungsten, nitrogen. This group is magnetic.	Contains enough nickel to make steel austenitic and non-magnetic. They usually contain twice as much chromium as nickel or vice versa; total alloy content at least 26%. Carbon is quite low.
Heat Treatment Respond to hardening, tempering, and drawing. Resulting physical properties depend on chemical analysis (principally carbon content).	Do not respond. 18% chromium toughened by long anneal at more than 1400° F., and air cooling. Avoid decarburizing the skin. 25% chromium gets best strength and toughness by rapid cooling from 1650°.	Do not respond to hardening by heat treatment. Must be rapidly cooled from soaking heat at 1800 to 2150° F. to retain austenitic structure free of carbides. (Brinell 140 to 170).
Toughness Are structurally dependable. After tempering are not brittle in notched sections or under impact.	Laminated structure, from coarse ferrite in ingot, causes low impact values, but proper rolling and heating gives adequate toughness in rods, bars, and sheets. Structure is refined by nitrogen.	Extremely tough at all temperatures down to liquid air. Dependable against shock except when corroded at grain boundaries (a preventable condition).
Grain Growth and Structural Changes at High Temperatures Not subject to excessive grain growth. Thoroughly dependable for supporting any load or shock within their carrying capacity up to 1400° F. Brittleness in plain chromium steels when cooled after long heating is avoided by addition of molybdenum.	The chromium-irons low in carbon and those high in silicon or aluminum (when cold worked) are subject to excessive grain growth, especially above 1900° F. Grain growth reduced by nitrogen. Long service at 800 to 950° F. makes them brittle when cold, although they are not brittle at working temperatures.	Alloys near the austenite-martensite border line tend to precipitate carbides at grain boundaries during service at 800 to 1600° F., losing some toughness and becoming susceptible to intergranular attack. This is controlled by very low carbon, by titanium or columbium, by increasing the chromium and nickel, or by prior "stabilization."
Strength at Elevated Temperatures Much better than straight carbon steel for temperatures up to 1000 or 1200° F. Retain tensile properties up to 750° F.	Heat resisting varieties quite tough at temperatures up to 1600° F. Superior in ductility to Group C but not in creep resistance.	Have high creep strength up to 1200° F. which is enhanced by tungsten or molybdenum. Toughness impaired in non-stabilized alloys by service at 800 to 1600° F.
Hot Working Qualities Readily forged, pierced, or rolled at 2000 to 1700° F. Preheat and soak stock at 1600° F. Plain chromium alloys air harden on cooling.	May be forged, rolled, or pierced. Should be heated quickly. Forge from 2200° F. down to 1750° F. On last heat continue cold working to 1400° F. to refine grain. Alloys do not air harden.	May be forged, rolled, or pierced. Preheat and soak at 1600° F., heat quickly to 2200° F., forge down to 1850° F. Hot short range: 1800 to 1300° F. Alloys do not air harden.
Cold Working Qualities Low carbon varieties can be easily cold drawn into wire, cold rolled, bent, formed, upset, coined, and deep drawn.	Can be cold drawn into wire, cold rolled, bent, formed, upset, coined, and deep drawn, especially when warm (300 to 500° F.).	Can be cold drawn into wire, cold rolled, bent, formed, upset, coined, and deep drawn. Work-harden twice as rapidly as Groups A and B.
Machinability Machine satisfactorily with properly designed tools when heat treated to 200 to 250 Brinell. Free-cutting grade contains zirconium sulphide.	Machine satisfactorily with properly designed tools. Cold working and high sulphur improve machinability.	Most difficult of all even with super high speed and carbide tools. Use sharp tools having greater top rake than usual, and cut continually. Free-cutting grade contains selenium and phosphorus.
Riveting Make excellent cold rivets. Air hardening, plain steels not recommended for hot rivets driven above 1500° F.	Extra precautions required to avoid brittle rivets. Conical heads should be cold upset on ground bars; rivets driven at 1425° F. into chamfered holes.	Excellent for either hot or cold rivets. Hot rivets may be driven at a high temperature (1900° F.).
Welding Properties Preheated parts can be welded with gas, electric arc, or resistance. Anneal immediately before weld air hardens. Little grain growth.	Can be welded. Anneal at 1450° F. to reduce embrittlement alongside weld. Those metals subject to grain growth are brittle adjacent to the weld. Those metals not subject to grain growth yield satisfactory welds.	Can be welded with gas, electric arc, or resistance, if carburization is avoided. Weld does not air harden and is very tough. Only the relatively low carbon or "stabilized" metal should be welded if article must resist corroding media.
Corrosion Resistance Increases with chromium content. Resists weather, water, steam, and many organic and inorganic corrodents when chromium is 11.5% or more. If carbon is relatively high, metal must be hardened and tempered (below 1000° F.).	Possess corrosion resisting properties superior to Group A. Especially good for nitric and other oxidizing acids.	Corrosion resistance depends largely upon total alloy content. Resists nearly all corrodents measurably better than Groups A and B; especially good for organic acids. Severe pitting may occur in stagnant chloride solutions under particles of foreign matter and along faying surfaces.
Scale Resistance Increases with chromium content. Generally useful for continuous temperatures up to 1200° F., and in some services up to 1500° F.	Superior to Group A, especially when chromium is above 25%; then resist reducing atmospheres up to 2100° F., oxidizing up to melting points, and sulphur gases up to 1800° F.	Excellent where combination of high temperature and corrrosion is to be met. High chromium alloys required to resist sulphurous gases.



Rennerfelt Furnace With Dolomite Lining and Chrome-Magnesite Roof Makes 1½-Ton Heats of High Chromium-Iron Alloys in 4 Hr. Heat is conserved during overnight shutdowns by asbestos mattresses

required, the nickel-rich alloys are the only ones suitable. They will resist thermal shocks as well as scaling. Long-time tests at elevated temperatures show very little structural change taking place, elongation being constant through several months. The nickel-rich alloys are also best for molten alkalis.

A considerable variety of melting furnaces were observed in American foundries. The majority of shops the author visited used basic electric furnaces. Some used acid furnaces and a few high frequency induction furnaces. One producer used an oil heated reverberatory furnace, and two used Detroit rocking furnaces. If the author were allowed to choose, he would install a small basic Heroult type in a jobbing foundry for making chromium steels from good scrap and ferro, to meet close specifications on analysis, or a high frequency furnace if a great deal of low carbon 18-8 was to be produced. In Sweden there are several high frequency furnaces in the latter duty, at least two of them having 5-ton capacity.

Details of Melting Practice

When melting stainless steels, the first thing to be considered is the avidity with which chromium heats take up gases. It is absolutely necessary that all raw materials be perfectly dry; otherwise hydrogen will go into the metal, and it is very hard to get out again. Then, strangely enough, too much silicon and too white a slag will give troubles, coming from what is called the "over-reduced condition." Many of the plants the author visited used cement for their slags to make a gas-tight cover.

Melting practices observed are various. A practice similar to the original one used in the American shop wherein the writer was employed many years ago is still operated by at least one large producer. Briefly, this is to melt down selected scrap, with about 1% of ore to have some boil. Add also 0.10 to 0.12% manganese as soon as the bath is molten. Boil 40 to 45 min. to drive the carbon very low (say 0.03%). Make the first test and if carbon is right, slag off; if carbon is too high, ore and boil again and then slag off. Next add a little low carbon ferromanganese and 0.15% silicon, make up the white slag, and close furnace tightly. If the second test shows killed metal, add preheated alloys with a little silicon, and tap at 3000° F.

While the author has no criticism to make of this practice in a large furnace, he would prefer the following general routine as better practice for a small shop:

Charge all iron and steel scrap and melt

Relative Corrodibility of Some Common Metals and Alloys

Compiled 1933 by Jerome Strauss, Vanadium Corp. of America

Class of Material	Nominal Composition							Atmospheres		Water					Oxidation Resistance Max. Safe Temp. °F.			Fruit, Vegetable Juices	Dairy Products	Other Food Products	Acids Moderate Concentration 5-15%					Alkalies		Salt Solutions Medium Concentration			Hot Sulphite Liquor	Dye Liquor	Refinery Crudes Below 400°F.	
	Carbon	Chromium	Nickel	Silicon	Copper			Sea Shore	Industrial	Domestic	Mine	Sea	Saline with H_2S	Brackish with Mn Cl	Wet Steam	Oxidizing Gases	Reducing Fuel Gas	Sulphur Rich Gas				HCl	H_2SO_4	HNO_3	Acetic	Phosphoric	1 to 20% Sol.	Fused	NH_4Cl	$MgCl_2$	$MgSO_4$			Sweet	Sour
Ingot iron or wrought iron	0.03				0.08			P	P	P	P	PF	P	F	F				P	P	P	P	P	P	P	E		P	F	F	P		F	P
Low C steel	0.10				0.08			P	P	P	P	F	P	F	F				P	P	P	P	P	P	P	E		P	F	F	P		F	P
Low C copper steel	0.10				0.25			F	G	P	F	F	P	F	FG				P	P	P	F	P	P	P	G		P	F	F	P		F	P
Hot galvanized iron & steel								G	G	F	F	G	F	F					P	P	P	P	P	P	P	F		P	P	PF	P		G	P
Calorized iron & steel								G	G	P	P	P				1650	1650	1650														P	F	FG	FG
Gray cast iron	2.8 graphite, 0.7 combined carbon							F	G	F	F	F							P	P	P	P	P	P	P	E	F	P	P	P	P	P	F	
High silicon iron	0.60			14.25				E	E	E	G	E							G†			F	E	E	G	G	E		G	G	G	P	P	F	
Nickel cast iron	3.30		3.50	1.50				F	G	P	P	F														E	FG				P	P	F	
Chromium cast iron	2.50	25.00		2.00				G	G	G	G	FG				1800	1800	1800																
Ni-Cr-Cu cast iron	3.00	2.00	14.00	1.50	6.00			G	G	G	G	G	F	F	G	1200	1200	1200	F			F	F	P	G	G	G	G	F	F	F	F	F	G	G
Nickel steel : Low Ni	0.18		3.00					F	F	F	P	F							P	P		P	P	P	P	E	G	P	F	F				
High Ni	0.30		28.00					G	G	G	FG	E							F			F	G	P	P	E		F	E	E				
Chromium steels : 5% Cr	0.15	5.00						F	F	F	P	P	P	P	F	1200	1200	1200	P			P	P	P	P	P	G		P	P	P	P	G	G
12% Cr	.10 max.	12.00						G	G	G	F	F		F	G	1400	1400	1400	G		G	P	P	G	G	F‡	E		P	F	G	P	E	
17% Cr	.10 max.	17.00						G	G	G	G	G		G	G	1600	1600	1500	G	G	G	P	P	G	E‡	P	E		G	G	G	F	F	E	E
17% Cr, 4% Mo	.10 max.	17.00				Mo 4.0		G	G																									
27% Cr	.50 max.	27.00						G	G	E	G	G		G	E	1900	1900	1800	E	G	E	P	P	E	F	G	G		E	E	E	GE			
Silcrome, (8% Cr, 3% Si)	0.45	8.25		3.50				G	G	F	F	F	F	F	F		1500		F			P	P	E	G		G					PG		
Stellite	3.0 max.	30.00				Co 55.0	W 15.0	E	E	E	E	E	E	G	E	2000	2000		E	E	E	F	G	E	G	E	E		E	E	E	G	G	E	E
Cr-Ni steels : 8-20	0.20	8.00	20.00					G	G	G	G	G				1600	1600					P	G	F	G	G	G	G				P		G	
18-8, 4% Mo	0.15	18.00	8.00			Mo 4.0		E	G	E	G	G	E	E	E							P		G	G	G	G		E	E	E	GE		E	E
18-8	0.10	18.00	8.00					E	G	E	G	G	E	G	E	1550	1550	300 to 1300	G	E	E	P	F	G	G	G	E	G	FG	E	E	GE	F	E	E
18-12	0.10	18.00	12.00					E	G	E	G	G										P	F	G	G	F	G					P		E	E
18-35	.50 max.	18.00	35.00	1.00				E	G	E	FG	G				1900	1900	1900	G			P	P	G	P	F	G	G				P			
25-12	.25 max.	25.00	12.00					E	G	G	E	G	E	G	E	2100			G	E	E	P	P	G	G	F	G	G	E	E	E	GE	G	E	
26-24	.15 max.	26.00	24.00	3.00				E	G	E	G	G	E	G	E	2100	2000		G	E	E	P	F	G	G	G	G	G	E	E	E	E	G	E	
Commercially pure Ni			99.20					E	G	E	G	E	G			1300	2000	P	G	GE	GE	G	G	P	G	G	E	E			G	P	P	G	
Nickel alloys : Monel metal	0.15		67.50	0.50	28.50	Mn 1.50		E	G	E	PE	E	G		E	900	2000	P	G	FE	FG	FG	G	P	G	G	E	E	G	E		P	P	G	E	F
Nichrome, 60-15	0.12	15.00	60.00					G	G	E		G				1475 to 2100		P	G			F	F	F	G	G	G					P	P			
Inconel, 14% Cr		14.00	80.00			Fe 6.0		G	G			G				2000	2000		E	E	E														
80% Ni, 20% Cr		20.00	80.00					G	G	E		G							G			F	G	P	G	G	E								
Hastelloy		14.00	58.00			Mo 17	W 5.0	E	E	E	G	E	E	E	E				E	G	G	G	FG	G	G	E	E	G	G	G	G	E	G	G	G
Commercially pure Cu					99.90			G	G	G	FG	G							FG	P	F	F	FG	P	FG	FG	FG		G			G	FG		
Copper alloys : Red brass					85.00	Zn 15.0		G	G	FG	FG	G							FG	P	P	P	FG	P	FG	FG	P		G			G	FG		
Tobin bronze					60.00	Zn 39.2	Sn .75	G	FG		F	G	F									P	F	P	F	F	F					G	F	FG		
Phosphor bronze					95.00	Sn 5.0	Zn 1.5	G	FG		F	G								P	P	P	FG	P	FG	FG	FG					G	FG			
Silicon bronze				3.00	95.00	Mn 1.0 or	Sn .5	G	G		FG	G							P	P	F	P	FG	P	FG	FG	FG	P				G	FG			
Aluminum bronze					90.00	Al 9.0	Fe .5	G	G		FG	G							FG	P		P	FG	P	FG	FG	FG						FG	G		
Nickel silver			20.00		75.00	Zn 5.0	Ni .5	G	G		G	G							G	P		F	G	P	G	G	G						FG			
Admiralty metal					70.00	Zn 29.0	Sn 1.0	G	G		FG	G							FG	P		P	FG	P	FG	FG	P						FG			
Commercially pure Al						Al 99.20		F	F	PG	P	F							G	G	G	P	P	P	F	P	P					P	F		
Commercially pure Sn										E																									
Commercially pure Pb					0.06	Pb 99.90		G	G	PG	G	G							P	P	P	F	G	P	P	G	P	P					P	F		

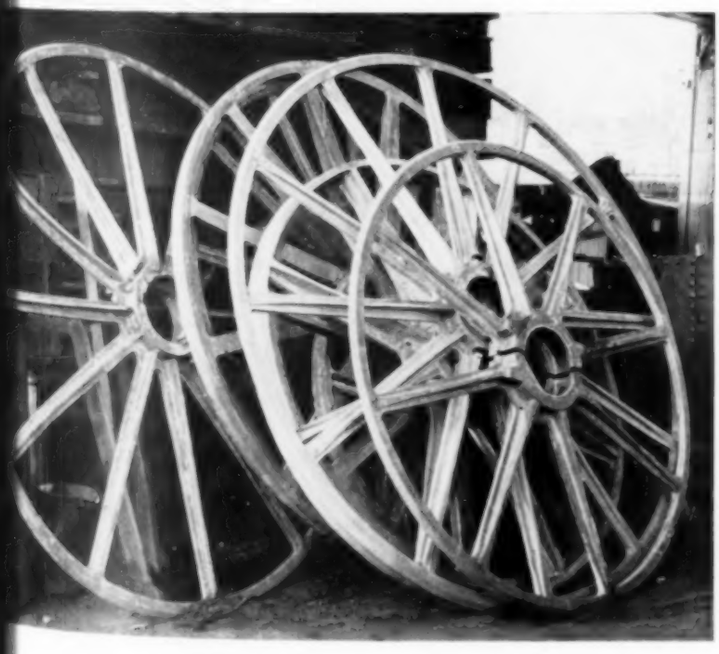
E = Excellent; almost unlimited service
G = Good; will give good service
F = Fair; only to be used in temporary construction
P = Poor
FG = F to G PG = P to G PE = P to E
† E at low and P at high concentration
‡ Below 500°C

down. Use a little lime and dry sand in the relationship of 3 to 1. Add some ore and let boil. Take most of the slag off, then add silicon and 0.015% zirconium (figured on the initial charge). Change slag from black to brown by using calcium-silicon alloy. Next add 0.2% of ferromanganese. Put in return iron and stainless steel scrap, keeping slag dark green. Put in more silicon-zirconium and change slag over to light green. Put in ferrochromium and heat bath to 2850° F. Then reduce power and tap at moderate temperature. If titanium is used as a grain refiner, do not add more than a few tenths per cent of 25% ferrocarbon-titanium; otherwise you will get a heavy boil and porous castings (probably carbon monoxide from the reaction between carbon in the ferro-alloy and oxides or oxygen dissolved in the bath).

A third method which is to be recommended is to charge ferrochromium with the stainless scrap and steel scrap in the furnace, using the one-slag practice. This is the safest method for tight castings.

If you want to use high nitrogen ferrochromium, detailed instructions available from the Electro Metallurgical Co. should be followed. The first additions will probably cause liberation of free nitrogen, but if the temperature is kept low, the gases will disappear after a while and the benefit of the nitrogen addition will appear quite satisfactorily.

Rangy Castings, Up to 8 Ft. Diameter, of High Chromium for Paper Mill Equipment Handling Dilute Bleaching Solutions



Hard Spots and Heat Checks

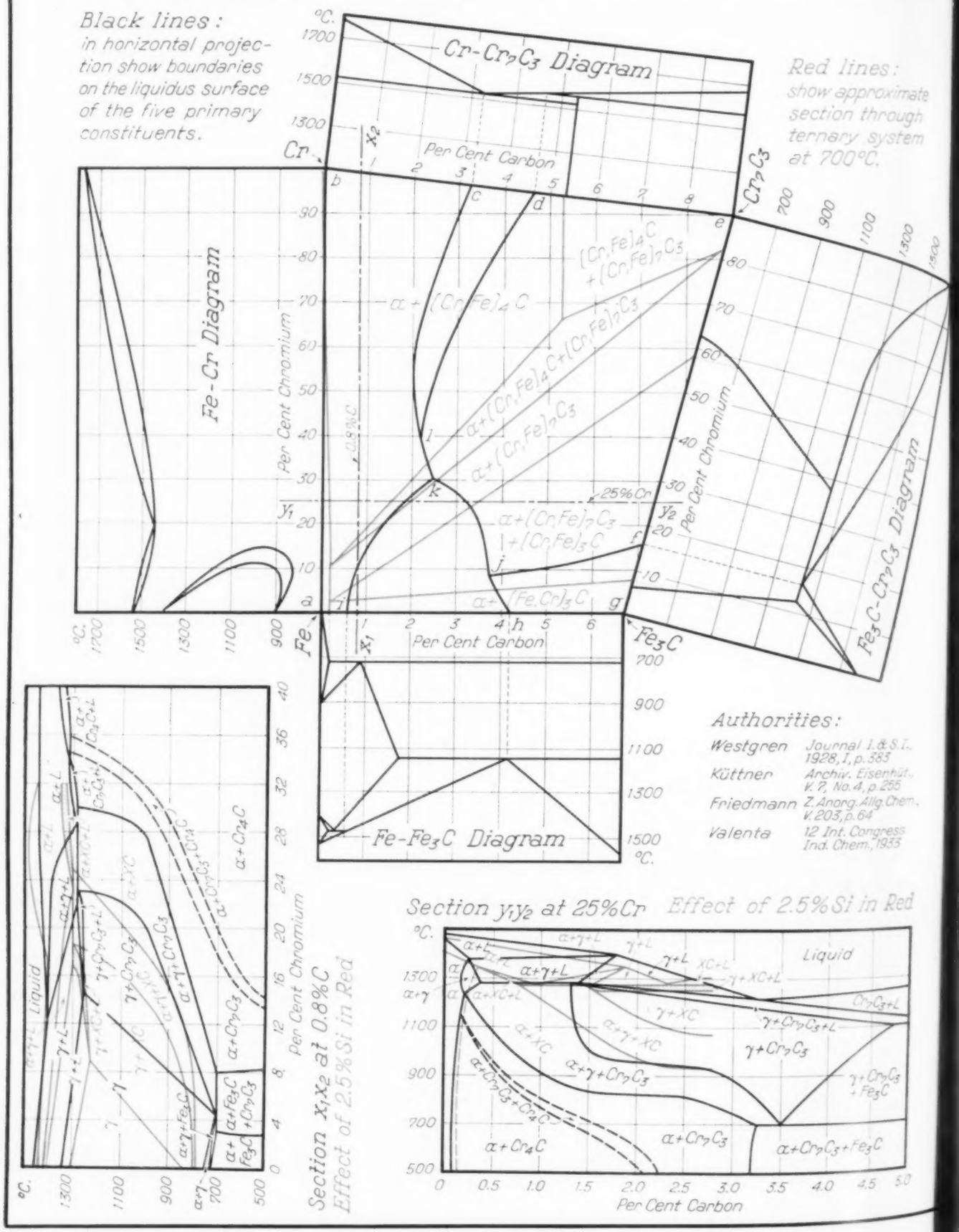
Hard spots in high chromium-iron castings can be softened somewhat by heating to 1450° F., 1 hr. per in. of metal (not less than 5 hr.). Furnace cool to 900° F. The use of low carbon ferrochromium is also recommended in several places. For making 100 lb. of the high chromium irons the raw materials used would be about 20 lb. steel scrap, 40 lb. return iron (alloy sprues and gates), 20 lb. stainless steel scrap, 20 lb. ferrochromium.

Heat cracks may be avoided by casting analyses outside the brittle phase, as shown on the structural diagram. Molybdenum is no "cure-all" but a valuable medicine. Skin-dried molds are used exclusively in America; since returning to Norway the writer has completely abandoned dried molds for skin-dried and has entirely avoided heat cracks, using gates and risers of about the same size and disposition as would be proper with common gray irons. It is also very important to shake out the castings quickly.

We pour chromium irons over the lip of the ladle. Teapot spouts are of great assistance here, but lacking ladles of that sort, we skim the slag carefully from the ladle and put a little dry sand on the hot metal. This forms a thick acid paste, excluding gas from the metal and yet easily held back by a rabble when pouring. This is a most important practical point, because otherwise the heavy, thick and refractory chromium oxide will find its way into the molds and usually gather around corners at the most dangerous places.

Pickling of castings was not observed frequently in American foundries. We use the following solution: 10% nitric acid, 3% hydrochloric acid, and 2% formaldehyde. But as long as you have your good cleaning machinery, you do not need to bother very much about pickling. Blasting with steel shot gives silver-gray castings and for heat resisting alloys the pickling is quite unnecessary, but for passivating the chromium-iron alloys against liquid or atmospheric corrosion it is no bad idea to use one bath of nitric acid and a water tank to clean the casting. This will dissolve all contaminating iron and help make the alloy still better.

Structural Diagram for Fe-Cr-C-Si

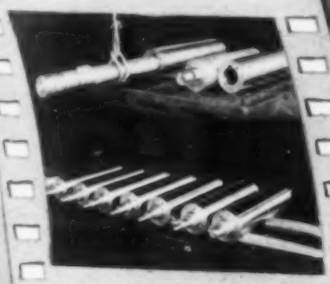


Authorities:

Westgren	Journal I. & S. I., 1928, I, p. 385
Küttner	Archiv. Eisenhütt., V. 7, No. 4, p. 255
Friedmann	Z. Anorg. Allg. Chem., V. 203, p. 64
Valenta	12 Int. Congress Ind. Chem., 1935

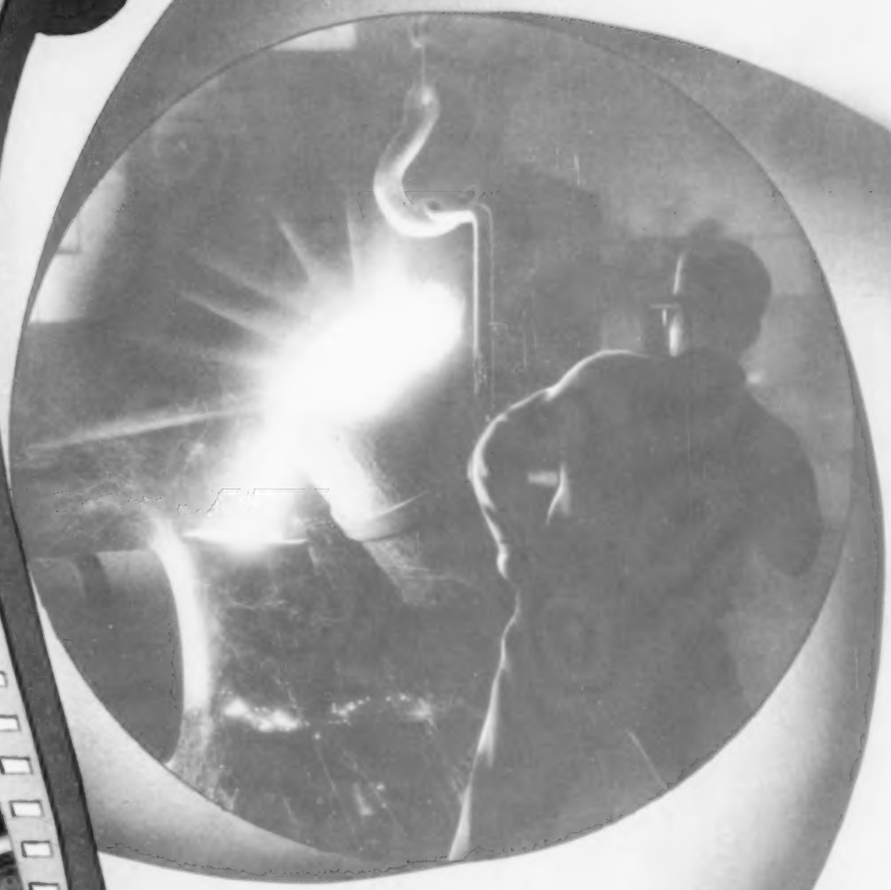
Group of rough castings . . . note clean appearance . . . long lengths . . . flanges and solid bars.

Finished machined pump liners for a large oil refinery and rough machined cylinder liners for engines.



Steel mill rollers, before and after, assembling and grinding.

A group of completely assembled 15" Dia. X 100" face Hot Strip Mill conveyor rolls.



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SPEED, combined with the Specific Gravity of the Alloy, creates centrifugal

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PRESSURE during the Full Cooling Cycle from the Molten to the Solid state results in a

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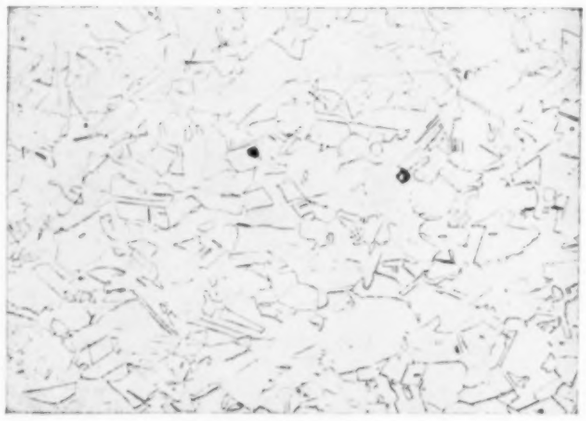
Centrifugally Cast Metals and Alloys

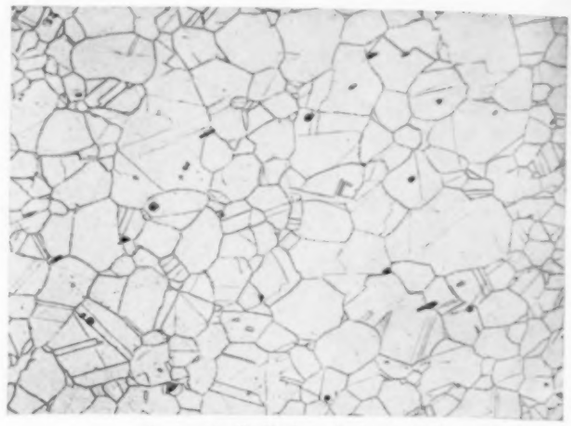
Microstructure of
Nickel and High Nickel-Chromium-Iron Alloys

Photomicrographs by courtesy of Research Laboratory, International Nickel Co.



Nickel, Hot Rolled

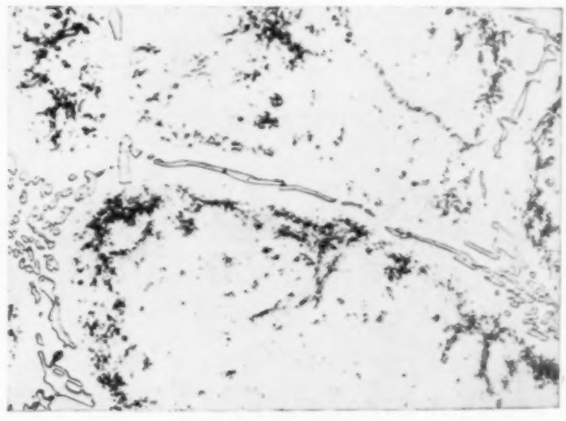
Etched with equal parts of nitric and acetic acid; magnified 100 diameters. Analysis: 0.12% C, 0.11% Mn, 0.03% Si, 0.10% Cu, 0.11% Fe, 0.005% S.



Inconel, Rolled and Annealed

One-quarter hard (Rockwell B-87), 0.062-in. strip. Etched in mixture of hydrofluoric and nitric acid; magnified 100 diameters. Nominal analysis: 80% Ni, 12 to 14% Cr, 6% Fe.

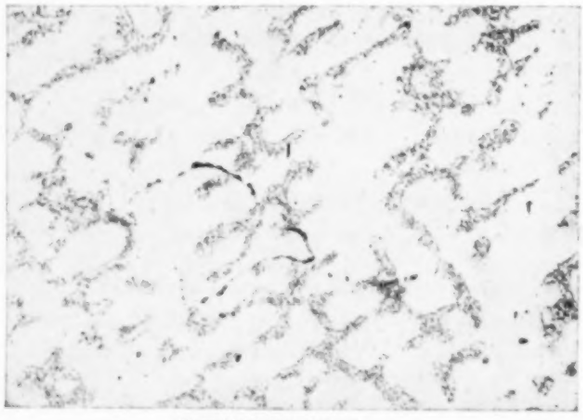
Magnified 100 diameters



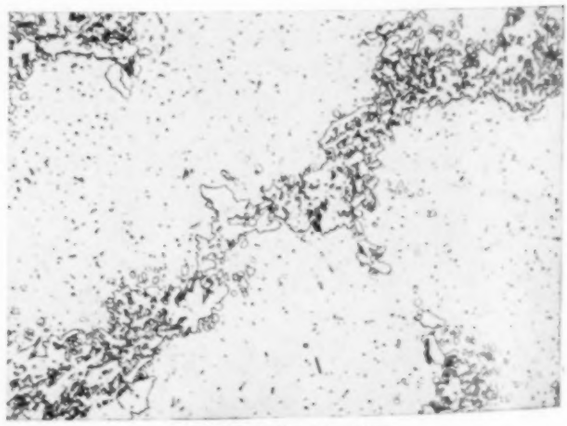
Magnified 500 diameters

Cast Alloy of Nichrome Type for Heat Resistance

¾-in. casting, etched in aqua regia. Analysis: 60% Ni, 15% Cr, 23.5% Fe, 0.5% C, 0.5% Mn, 0.5% Si.



Magnified 100 diameters



Magnified 500 diameters

Cast 35-18 Alloy for Heat Resistance

¾-in. casting, etched in aqua regia. Analysis: 35% Ni, 18% Cr, 44.5% Fe, 0.5% C, 0.5% Mn, 1.5% Si.